APPALACHIAN WORKSHOP AND RESEARCH UPDATE

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Improving Small Ruminant Grazing Practices

Proceedings

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Foreword

The Appalachian Region represents one-tenth of the land area of the United States. It extends more than 1,000 miles southwestward from southern New York to the northern areas of Georgia, Alabama, and Mississippi. It encompasses all of West Virginia and parts of Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Maryland, Ohio, Pennsylvania, and New York. The topography of the area varies from hilly to mountainous with relatively little flat land (45% mountains and high plains, 38% hills and low plateaus, 17% plains and lowlands). Elevation ranges from slightly above sea level to 6684 feet at Mt. Mitchell, NC. Average rainfall in the Region ranges from 30 to 60 inches. Rainfall distribution is fairly uniform throughout the year, though large spatial gradients exist in mountainous areas. Mean annual temperatures range from 45 to 60 ºF. The average growing season is between 160 and 200 days; however, the average frost free period at higher elevations is about 120 days. Most farms in the Appalachian Region are small, less than 200 acres in size. Grassland and pasture account for about one-quarter of the land use and most of the agricultural acreage in the Region. Livestock production is the most common farming enterprise because most of the farm land is too steep for crop production. Historically, agriculture has been limited by the lack of profitable systems ideally suited to the Region.

Today there is expanding demand for pasture-based livestock products, and greater profit potential may be realized through opportunities in niche markets for chevon and lamb. Traditional sheep, hair sheep, and meat goat industries are growing rapidly in the Appalachian Region as lambs and goat kids under a year of age and weighing 60 to 70 pounds are sought by meat packers for ethnic markets. Increasing demand provides production incentives and reinforces the long-standing need for development and refinement of grazing practices for small ruminant production on hill-land farms in humid, temperate climates. Information on forage and small ruminant management strategies to maintain healthy livestock and achieve desirable growth rates and carcass quality is fundamental to economic success. Technologies must also protect the integrity of the Appalachian environment.

Goals of the Appalachian Farming Systems Research Center and its partner, the Medicinal Botanicals Program at Mountain State University, are to discover regionally adapted forage plants, develop novel pasture systems, and identify bioactive plant resources that can satisfy nutritional and health needs of meat goats and sheep produced in Appalachia. The research involves a systematic approach that combines laboratory, greenhouse and field experimentation techniques. The innovations in small ruminant grazing practices for Appalachia described in these Proceedings include: finishing small ruminants on pasture, silvopasture as a natural choice for small ruminants, non-traditional and traditional forages for central Appalachia, plant constituents for control of gastrointestinal parasites, and opportunities for use of artemisia in small ruminant production.

Finishing Lambs and Goat Kids on Pasture

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Abstract

Producing goats and lambs for ethnic markets offers an economic opportunity for small farm producers in the Appalachian Region of the U.S. There are a variety of forages used in goat and sheep production systems. Overall, nutrients available to ruminants depend upon the types and combinations of plant resources grown. Weaned goat kids require 65-68% total digestible nutrients (TDN) and 12-14% crude protein (CP) in the diet while weaned lambs require 75-81.8% TDN and 14.5-16% CP in their diet. Rotational stocking of livestock on paddocks can improve forage use, maintain plant persistence and productivity, and provide a high nutritive value forage (especially TDN and CP) for finishing goats and sheep on pasture. When finishing goat kids and lambs on pasture, producers can maintain low production costs and have options to sell animals at different times and at a variety of weights that will satisfy niche markets. Meat packers who supply meats to ethnic markets typically desire healthy goat kids and lambs under 1 year of age and weighing 60 –70 pounds without excessive fat. Other sectors of the market desire younger animals weighing 25-50 pounds. Research at AFSRC in 2007 indicated that goats finished on alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.) or orchardgrass (*Dactylis glomerata* L.) produced desirable body weights and carcasses for ethnic markets. Katahdin lambs and Boer x Kiko meat goat kids finished on an orchardgrass-red clover-white clover (*Trifolium repens* L.) pasture with and without whole cottonseed (*Gossypium hirsutum* L.) supplementation produced desirable body weights and carcasses for ethnic markets. Heavier weight (> 80 lbs) Suffolk lambs finished on pasture with and without supplementation may fit better into the traditional or Kosher meat markets. Also in this study, the number of anthelmintic doses administered for control of the gastrointestinal parasite *Haemonchus contortus* was reduced 38% when using the FAMACHA© system.

Background

Meat goat, hair sheep, and traditional sheep industries are a vibrant component of small farm production systems in the Appalachian Region. These systems help produce meats to satisfy the demand from the expanding ethnic markets in the U.S, including Middle Eastern, Hispanic, European, African, and Caribbean cultures. Producing fresh meats for ethnic markets offers an income generating opportunity for small farms. The viability of any livestock enterprise is depends on minimizing production costs while producing a consistent and desirable product.

Small Ruminant Breeds

Interest in meat goat production has increased since the introduction of the Boer meat-type goat from South Africa into the U.S. about 20 years ago. Goats in the U.S. prior to this time were Spanish-type goats, mostly decedent from dairy goat breeds. The Kiko, a meat-type goat from New Zealand, was introduced into the U.S. about 10 year ago and is gaining popularity in the southeastern U.S. (Browning et al., 2006) because of the breed's hardiness, survivability, low maintenance input, maternal traits, fast growth, and resistance to gastrointestinal parasites.

Traditional meat-type sheep breeds in the U.S. include Suffolk, Hampshire, and Dorset. Wool-type breeds include: Merino, Columbia, and Rambouillet. In recent years, interest has centered on the production of hair sheep because these sheep do not need to be sheared and have resistance to gastrointestinal parasites (Burke and Miller, 2004; Jones, 2004). Hair sheep breeds include: Katahdin, Dorper, and St. Croix.

Ruminants

Goats, sheep and cattle are ruminants, which means each species has a four-compartmented stomach (rumen, reticulum, omasum, and abomasum), each with a specialized purpose that enables these species of livestock to thrive on grasses, legumes, forbs (weeds and herbs), and browse (woody plants, shrubs, vines, brambles, and trees) via microbial fermentation in the rumen.

Forages

Forage is a general term that includes herbages, forbs, and browse. Herbages are grasses and grass-like plants (does not include the grain). Forbs are broadleaf plants that include legumes, herbs, and weeds. Legumes are considered a separate specialized group of forbs. Browse is defined as leaf and twig growth of shrubs, woody vines, trees, cacti, and other non-herbaceous plants.

There are a variety of forages used in goat and sheep production systems. In the Appalachian Region traditional cool-season grasses include orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.), bluegrass (*Poa pratensis* L.), and traditional legumes include white clover (*Trifolium repens* L.), red clover *(T. pratense* L.) and alfalfa (*Medicago sativa* L.). Non-traditional forages are used during summer and late fall to fill voids when traditional forages are less productive. Non-traditional forages include: warm-season grasses such as bluestems (*Andopogon spp*.), switchgrass (*Panicum virgatum* L.) and corn (*Zea mays* L.); summer annual grasses such as pearl millet [*Pennisetum glaucum* (L.) R. Br.], sorghum (*Sorghum* spp), crabgrass (*Digitaria sanguinalis*); legumes such as sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don] and annual lespedezas (*Kummerowia* spp); and forbs such as chicory (*Cichorium intybus* L.). Browse plants such as multiflora rose (*Rosa multiflora* Thunb.), yellow honey suckle (*Lonicera flava* Sims), autumn olive (*Elaeagnus umbellata* Thunb.) can also be utilized during this summer period. Fall grazing includes: annual ryegrass (*Lolium multiflorum* Lam.); forage brassicas (*Brassica* spp. including turnips, rape, and kale); and winter annual cereals such as wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), and triticale (*xTriticosecale rimpaui* Wittm.).

Forage Nutritive Value

Overall, nutrients available to ruminants depend upon the types and combinations of plant resources. Traditional assessment of plants for nutritive value includes laboratory analyses for energy [usually expressed as total digestible nutrients (TDN)]; crude protein (CP)]; digestibility [in vitro organic matter disappearance (IVOMD)]; neutral detergent fiber (NDF) and acid detergent fiber (ADF)]; fats; minerals; and vitamins.

Weaned goat kids require 65-68% TDN and 12-14% CP in the diet which represents a TDN:CP ratio range of 4.9-5.4. While weaned lambs require 75-81.8% TDN and 14.5-16% CP in their diet which represents a TDN:CP ratio range of 5.1-5.2. Older, mature does and ewes have lower dietary requirements.

Browse such as honeysuckle can supply 72% TDN and 16% CP for goats and sheep. Turner and Foster (2000) reported that while CP and IVOMD concentrations in autumn olive, Morrow's honeysuckle (*Lonicera morowii* Gray), and multiflora rose were variable over the growing season, these plants were considered of high nutritive value for goats. When averaged across the growing season, CP was 26.5% (autumn olive), 16.7% (multiflora rose), and 14.5% (Morrow's honeysuckle) while IVOMD was 63.2% (autumn olive), 67.0% (multiflora rose), and 68.5% (Morrow's honeysuckle).

Cool-season grass pastures and hays (such as tall fescue, orchardgrass, Kentucky bluegrass) typically supply 58% TDN and 12% CP while legume pastures and hays (alfalfa, red clover, white clover) can supply 62% TDN and 18% CP. Orchardgrass pasture maintained in a vegetative stage (boot stage to early bloom) can supply 65% TDN and 18% CP whereas a more mature sward (more seed head) supplies 50% TDN and 8% CP. Maintaining plants in vegetative stages as compared to more mature stages (seed head) can be accomplished with grazing management practices.

Intensive Grazing Management

Grazing allows the animals to harvest the forage and is usually cheaper than feeding purchased hays. Intensive management generally involves a grazing plan that synchronizes duration of the grazing interval with the growth characteristics of the plant stand, by moving or adjusting the number of grazers on a given land area. Intensive grazing management can maintain plant persistence and productivity, and high nutritive value, especially TDN and CP, for improved forage utilization by grazing livestock. Producers can couple different methods of stocking for successful forage management and improved animal production. Many producers have implemented rotational stocking of livestock on pastures to improve overall forage utilization to achieve more uniform distribution of fecal and urinary nutrients for plant growth.

With rotational stocking, a large pasture is typically divided into smaller grazing areas termed paddocks, then a specified number of livestock are allotted to the first paddock, allowed to graze for a period of time, moved to the second paddock, and so on throughout the grazing season. With this type of management, paddocks are rested which allows forages time to regrow. This system helps to maintain forages with high nutritive value for sheep and goats, especially for finishing weaned kids and lambs which have higher nutrient requirements compared to mature animals.

Markets for Goats and Sheep

For traditional markets, lambs have been finished to 90-120 lbs. Meat packers supplying meats to ethnic markets (especially Halal) typically desire healthy goat kids and lambs under a year of age and weighing 60 –70 pounds without excessive fat. Other sectors of the ethnic markets desire younger animals weighing 25-50 pounds. With the dressing percentage around 50%, these weights of live animals produce carcasses weighing 15-35 pounds. Many ethnic groups traditionally purchase a whole carcass.

Producers have the option of selling goats and sheep at lighter weights to satisfy the needs of ethnic markets, local specialty meat markets, local restaurants, custom BBQ shops, or individuals. Markets for goats include: suckling kid (4-6 weeks of age); weanling kid (4-6 month of age); barbequing kid (6-12 month of age), and older animals (usually cull females). There are markets for young mature bucks.

Major ethnic meat markets are for Halal- or Kosher-harvested animals. These markets involve a religious ceremony associated with harvesting chevon, lamb, beef, or poultry for human consumption. Direct marketing of live animals for fresh meat is a niche opportunity for famers in the USA.

Weight Gain and Carcass Parameters

In general, forages are energy limiting and animals finished on pasture without energy supplementation gain weight slowly and produce leaner carcasses than animal finished in the feedlot on high grain diets. Site of fat deposition within the carcass and fat composition are related to the diet and breed of animal. Hair sheep (Horton and Burgher, 1992), and meat goats (Warmington and Kirton, 1990) yield lightweight carcasses with less subcutaneous fat cover and more internal fat compared to traditional sheep breeds (i.e. Suffolk, Hampshire) of the same age. Ruminants grazing legumes often have higher liveweight gains compared to forage grasses (Karnezos et al., 1994). Feeding diets high in fiber resulted in slower goat growth rates compared to high concentrate diets (Mahgoub et al., 2005).

In pen feeding studies with Spanish kids offered grass or alfalfa hays and a corn-soybean meal supplement, Wildeus et al. (2007) reported that goat average daily gain, carcass weight, and dressing percentage increased as forage nutritive value increased (grass hay vs alfalfa hay). Wether goats had greater ribeye area than bucklings or doelings. Wethers also had greater back fat than bucklings; doelings were intermediate. Internal fat was highest in doelings, intermediate in wethers, and lowest in bucklings. In a second pen feeding study with Boer and Boer crossbred wethers, ADG and dressing percentage was higher for kids offered alfalfa hay plus supplement compared to grass hay plus supplement; there were no differences in other carcass characteristics.

ARS-AFSRC Research Summary

Trial 1. Meat goats finished on alfalfa, red clover, or orchardgrass pasture.

In 2007, seventy-two growing meat goat wethers (at least 75% or greater Boer breeding) were randomly assigned to three pasture treatments: alfalfa, red clover, or orchardgrass that were each replicated three times, at a stocking density of 16 kids/ac (8 kids/pasture). Each pasture was 0.5 ac subdivided with electrical fencing into ten 0.05-acre paddocks for rotational stocking management based on a target 4-d occupation period.

Grazing began on 6 June and continued until 11 Sept 2007. Animals had access to water and mineral supplement at all times and were dewormed every 30 d with a combination (one from each anthelmintic class: benzimidazole, tetrahydropyrimidine and macrocyclic lactone) of orally administered anthelmintics.

At the end of the grazing season, animals were processed according to traditional Halal protocol. Carcasses were stored overnight for 12 hr in a walk-in cooler maintained at 34^{o} F prior to recording carcass data. The ribeye area (REA) and backfat (BF) were recorded from the right and left sides of the carcass and averaged. Chilled carcass wt and leg, lean quality, and overall conformation scores were recorded. Dressing percentage was calculated using the chilled carcass wt divided by final shrunk body weight (BW).

Table 1. Trial 1--Performance and carcass data when meat goat wethers were finished on alfalfa (ALF), red clover (RCL), or orchardgrass (OGR) pastures in 2007.

Item[z]	ALF	RCL	OGR	*P* value
Begin BW, lb	49.2	49.8	49.2	>0.10
Final BW, lb	63.7a[y]	59.9a	54.8b	<0.001
ADG, lb/d	0.22a	0.15b	0.13b	<0.001
Carcass Wt, lb	29.6a	26.5b	23.7c	<0.001
Dressing %	46.4a	44.2b	43.0b	<0.001
REA, sq. in.	1.40a	1.23b	1.13b	<0.001
BF, in.	0.07a	0.06b	0.05b	<0.01
Leg Score	10.4a	10.2a	9.6b	<0.001
Lean Score	11.0a	11.3a,b	10.7b	<0.05
Conformation Score	10.7a	10.5a	10.0b	<0.01

[z] BW = body weight; ADG = average daily gain; REA = ribeye area; BF = backfat.

[y]Means in the same row without common letters differ by the *P* value listed.

Final BW were greater for goats grazing alfalfa and red clover compared to those grazing orchardgrass (see Table 1). Overall ADG was greater for alfalfa compared to red clover and orchardgrass which were similar. Chilled carcass wt followed a trend of alfalfa > red clover > orchardgrass. Dressing percentage of red clover and orchardgrass was similar, and both were greater than alfalfa. The REA and BF thickness was higher for kids finished on alfalfa compared to red clover and orchardgrass. Leg score and conformation score followed a trend of alfalfa > red clover > orchardgrass; lean score was greater for alfalfa compared to orchardgrass; red clover was intermediate.

Trial 2. Traditional lambs, hair-sheep lambs and meat goats finished on pasture with and without supplementation.

A mixed sward of orchardgrass, red clover, and white clover was used for this experiment in 2007. Hay was harvested from all pastures in May 2007, and nitrogen fertilizer (33 lb N/ac) was broadcast after haying. The area was divided into six grazing pastures (each 1.5 acres) using electrical fencing; each of the six 1.5-acre pastures was subdivided into three grazing paddocks each containing 0.5 ac.

Thirty-six Suffolk crossbred lambs, 36 Katahdin lambs, and 36 Boer x Kiko meat goat kids were used. All kids and lambs were wethers of the same age (born 1-15 March 2007). Lambs and kids were weighed and assigned to six groups; each grazing group contained six Suffolk, six Katahdin, and six goat wethers. A group of lambs and kids grazed pastures together at a stocking density of 18 animals per 1.5-acre pasture (12 animals per acre). Each pasture was 1.5 ac in size and was subdivided into three 0.5-ac paddocks for rotational stocking management based on a target 21-d occupation period. Paddocks were mowed to a 4-in stubble height immediately after each occupation.

Three groups were supplemented with whole cottonseed (*Gossypium hirsutum* L.; WCS) at 0.5% BW daily throughout the experiment whereas the other three animal groups were not offered WCS supplement. Animals were weighed every 14 d, BW recorded, and supplement adjusted after each weigh day.

Grazing occurred from 29 June until 25 Sept 2007. Animals had access to water and salt-mineral supplement at all times and were dewormed only at the beginning of the study each year with a combination of orally administered anthelmintics (benzimidazole, tetrahydropyrimidine and macrocyclic lactone). After the initial deworming, only individual animals were administered anthelmintics when FAMACHA© eyelid score was 3 or greater; eyelid scores were determined every two wk.

Performance and carcass data are presented in Table 2. Overall as the season progressed, final BW and ADG were greater for WCS supplemented than unsupplemented animals and followed a trend of Suffolk > Katahdin > Goat. There were no treatment effects on carcass wt., dressing %, REA, BF, or leg, lean, or conformation scores. There was a breed effect on all parameters that followed a trend of Suffolk > Katahdin > Goat.

Table 2. Trial 2--Performance and carcass data when Suffolk (SX) lambs, Katahdin (KA) lambs and meat goat (GX) kids were finished on pasture with and without whole cottonseed supplement in 2007.

	--No Supplement--			---Supplement----			Supplement[y] Effect	Breed[x] Effect
Item[z]	SX	KA	GX	SX	KA	GX	*P* value	*P* value
Begin BW, lb	58.3	54.8	33.9	57.1	53.5	32.2	>0.10	<0.001
Final BW, lb	76.5	71.2	40.5	85.3	71.7	42.5	<0.01	<0.001
ADG, lb/d	0.20	0.18	0.07	0.32	0.20	0.12	<0.001	<0.001
Carcass Wt., lb	39.6	38.4	19.0	42.7	36.5	20.6	>0.10	<0.001
Dressing %	51.7	54.0	47.0	49.9	50.9	48.5	>0.10	<0.001
REA, sq. in.	1.92	1.72	0.97	1.97	1.70	0.99	>0.10	<0.001
BF, in	0.05	0.10	0.03	0.06	0.09	0.03	>0.10	<0.001
Leg Score	11.4	12.3	9.8	12.0	11.9	9.7	>0.10	<0.001
Lean Score	12.3	12.3	10.7	12.4	12.7	10.7	>0.10	<0.001
Conformation Score	11.3	12.1	9.8	11.9	11.8	9.7	>0.10	<0.001

[z]BW = body weight; ADG = average daily gain; REA = ribeye area; BF = back fat.

[y]Overall effect due to supplementation at *P* value listed; if *P* > 0.10, then not significant.

[x]Overall effect due to breed at *P* value listed.

Also in this study, the number of anthelmintic doses administered was reduced 38% when using the FAMACHA© system. Theoretically had the goats and lambs been dewormed every 30 days in July, August and September this would have resulted in a total of 324 doses of anthelmintic used. With the FAMACHA© system and administering dewormer only when individual animals scored a 3 or greater during this 90-d period, we used 200 doses of anthelmintic (104 doses in the unsupplemented groups and 96 doses in the supplemented groups).

Summary

In our studies, goats finished on alfalfa, red clover, or orchardgrass produced desirable body weights and carcasses for the Halal ethnic market. Katahdin lambs and Boer x Kiko meat goat kids finished on pasture with and without whole cottonseed supplementation produced desirable body weights and carcasses for the Halal ethnic market. Heavier weight (> 80 lbs) Suffolk lambs finished on pasture with and without supplementation may fit better into the traditional or Kosher meat markets. The FAMACHA© system can be used to reduce the amount of dewormers administered to goats to effectively control barberpole worm (*Haemonchus contortus*).

Current Research

In May 2009, a meat goat pasture finishing study was initiated. Meat goat wethers (avg initial wt 45 lbs) graze: 1) prairiegrass (*Bromus willdenowii* Kunth.) interseeded with red clover; 2) prairiegrass interseeded with birdsfoot trefoil (*Lotus corniculatus* L.); or 3) prairiegrass interseeded with chicory. Parameters currently being evaluated include: forage mass, forage nutritive value, goat body weight, average daily gain, blood parameters, FAMACHA© scores, fecal egg count, carcass parameters, and meat quality.

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Silvopasture: A Natural Choice

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Abstract

The Appalachian region is one of the most beautiful areas of the world. The mosaic of open areas (pasture and hayfields) and forestland is very productive in terms of animal and timber products. Livestock production can be improved through better herbage and animal management with Appalachian farmers being most adept at both. Woodlot management can increase economic return, species diversity, and farm aesthetics especially through the introduction of sustainable forage species. Silvopasture must have adequate solar radiation reaching ground level to ensure maximized production and quality herbage. Once established, silvopasture with similar fertility management and total diameter at breast height (DBH) values of approximately 50 to 65 feet per acre will produce about 60% the dry matter of open pasture. Animal performance can be expected to be equivalent between pasture types with lambs averaging about 0.20 lb per day gain under our management scheme. Differences in herbage nutrient profiles between pasture types may prove to be advantageous from an animal production and environmental standpoint. Research is currently being conducted to develop management strategies.

Introduction

The Appalachian region is one of the most beautiful areas of the world. The mosaic of open areas (pasture and hayfields) and forestland is very productive in terms of animal and timber products. Livestock production can be improved through better herbage and animal management with Appalachian farmers being most adept at both. Woodlot management can increase economic return, species diversity, and farm aesthetics especially through the introduction of sustainable forage species. Silvopasture development within Appalachia is a “Natural Choice” to improve farm production and value. Considerations and details with regards to silvopasture development are included in publications by Neel and Belesky (2003) and Neel et al., 2008.

Herbage Production

Research conducted within a pine woodlot by scientists and technicians at the Appalachian Farming System Research Center has shown that herbage production increases as trees are removed from the site. The selective thinning allows more sunlight to reach the woodlot understory where forage grasses can grow (Neel et al., 2008). Maximum herbage production was attained when solar radiation at the soil surface under a tree canopy was 80% of that occurring in the open. Although maximum herbage production was attained, it was approximately 42% of the amount of forage produced in an open pasture during the same year (Neel et al., 2008).

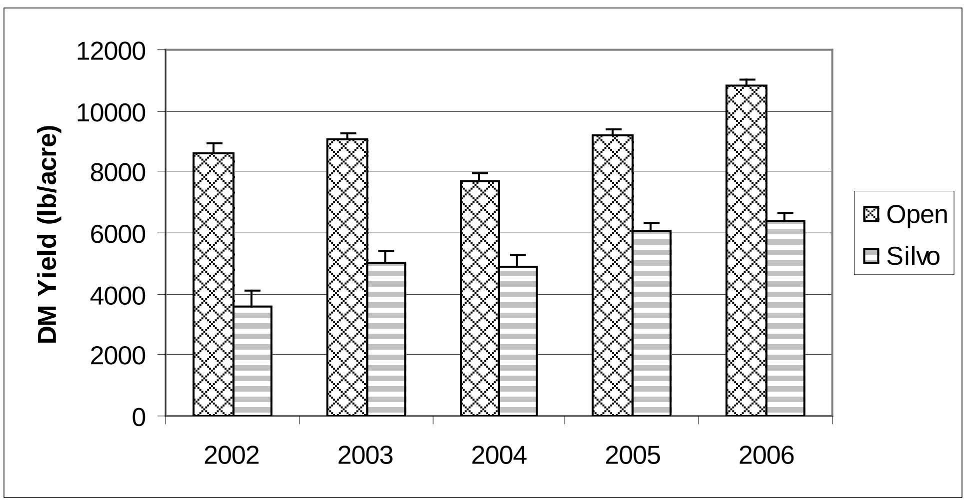

Figure 1. Open and silvopasture yield across years, presented as dry matter per acre (lb).

Figure 1 shows dry matter production within open and hardwood silvopasture across years. Open pasture produced more dry matter during all years with the magnitude being greatest during the first 2 years following establishment. The least productive year for open pasture was 2004. This was an extremely wet year with rainfall being evenly distributed across the growing season. Low solar radiation because of cloudy conditions may have reduced herbage yield. Open pasture yield ranged from 3.8 to 5.4 tons per acre while yields from silvopasture ranged from 1.8 to 3.2 across all years. In 2003, we decided that more trees within silvopasture had to be removed in order to ensure forage stand sustainability. During the winter and early spring of 2004, tree total diameter at breast height (DBH) per acre was reduced in silvopasture by about 33%. Generally, our experience shows that DBH should range from about 50 to 65 ft per acre to ensure forage sustainability and maximized production. Desired DBH is influenced by stand maturity, slope and aspect, and tree species. These factors should be taken into account when developing silvopasture and deciding when and how trees should be cut.

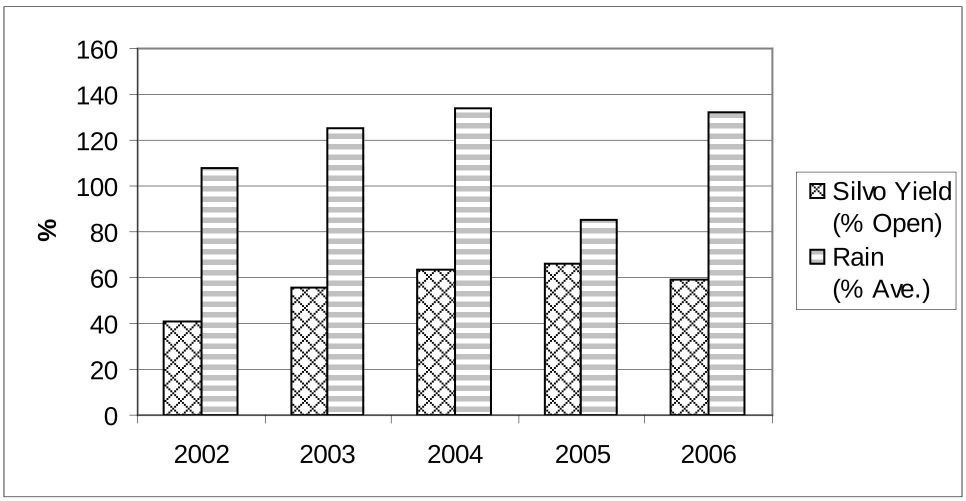

Figure 2. Silvopasture yield and rain amount presented as a percentage of open pasture yield and average rainfall amount respectively.

Figure 2 presents silvopasture yield and growing season rainfall as a percentage of open pasture yield and average rainfall respectively. Some people think that silvopasture should have an advantage over open pasture during dry and hot periods because the tree canopy buffers temperature extremes and minimizes the loss of soil moisture. The years of 2003, 2004 and 2006 were extremely wet growing seasons while 2005 was very dry. Across those years silvopasture yield averaged 61% of open pasture (with low variability), indicating no advantage for silvopasture in either wet or dry years. However, given that 2003 and 2004 were wet years and yield as a percentage of open jumped from 56 to 64%, opening of the canopy prior to the 2004 growing season seems to have improved productivity in relation to open pasture and was likely due to increased solar radiation reaching ground level. We noticed at the end of the 2003 growing season the need for the tree stand to be thinned if forage sustainability was to be achieved.

Herbage Quality

A vital indicator of herbage value is its nutrient profile. When forage plants don't receive enough sunlight, normal growth is not observed and nutrient content can be compromised. Under low light conditions, herbage crude protein can be excessive, nitrate deleteriously high, sugar content low, and energy content is not balanced with protein (Neel et al., 2008). Herbage with such a nutrient profile can reduce animal intake and performance, lower animal nitrogen capture and increase excretion, and in the case high nitrate, result in animal loss. Silvopasture must have adequate solar radiation reaching ground level to ensure maximized production and quality herbage.

Animal Performance

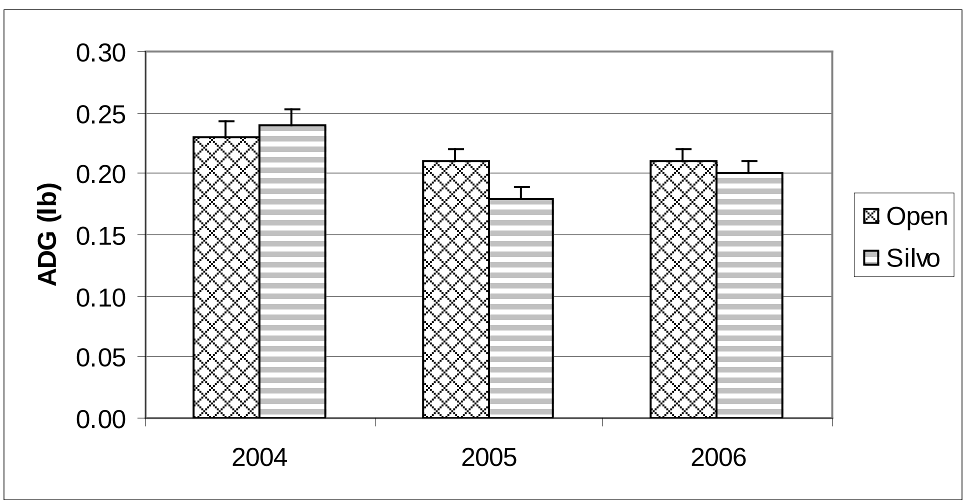

Figure 3. Lamb performance across years presented as average daily gain (ADG) in pounds.

Figure 3 presents lamb performance on open and silvopasture across years. It has been suggested silvopasture may be advantageous to animal performance because of reduced stress on grazing animals during hot periods. We did not detect any differences in animal performance between pasture types. Grazing animals in our experiments did not receive supplemental feed, yet obtained very respectable gains for young lambs on pasture.

Hardwood silvopasture herbage has higher levels of crude protein compared to open pasture at corresponding times throughout the growing season (Neel et al., 2003; Neel and Belesky, 2006). This higher crude protein level seemed to cause increased blood urea nitrogen (BUN) in lambs that suggested excess nitrogen availability to the animal (Neel and Belesky, 2006). Our current research is trying to find ways to use this difference in herbage nutrient profile to improve on-farm nutrient utilization efficiency.

Conclusion

Once established, silvopasture with similar fertility management and total DBH values of approximately 50 to 65 feet per acre will produce about 60% of the dry matter produced in open pasture. Animal performance can be expected to be equivalent between traditional and silvo-pasture types with lambs averaging about 0.20 lb per day gain under our management scheme. Differences in herbage nutrient profiles between pasture types may prove to be advantageous from an animal production and environmental quality standpoint. Ongoing research is underway to develop more efficient and easily applied management strategies.

Acknowledgments

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Non-traditional Forages for Central Appalachia

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Abstract

Small ruminant forage research at AFSRC is designed to improve forage and pasture management for small ruminants, especially as related to control of gastrointestinal nematode (GIN) parasites. Alfalfa pasture produced better meat goat weight gains than orchardgrass, but red clover pasture was difficult to maintain in a pure stand. Fall-stockpiled prairie bromegrass produced excellent weight gains in lambs. Chicory cultivar and sesquiterpene lactone concentrations did not affect forage palatability for goat kids. Phosphorus fertilization improved chicory yields when soil test P was less than 47 lb/acre. Forage brassicas did not directly inhibit GIN, but provided an alternate source of nutritious forage and a first step in renovation of declining perennial pastures.

Introduction

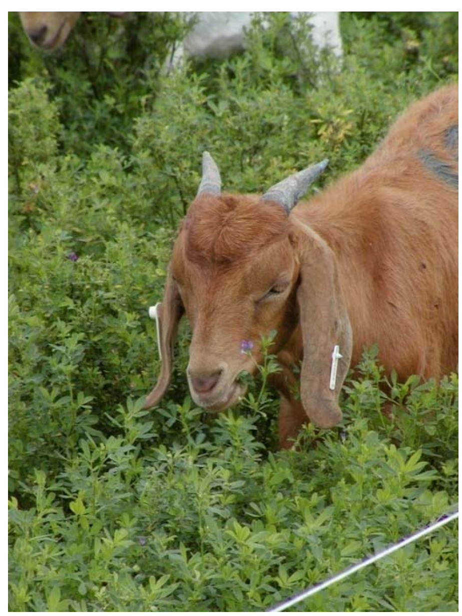
Small ruminant forage research at AFSRC is designed to improve forage and pasture management for small ruminants. An important non-traditional aspect of our research is natural control of GIN, particularly of blood-sucking species like barber pole worm (*Haemonchus contortus*) which cause significant losses to producers. Animals on pasture are exposed to a continual source of GIN infection because eggs shed in feces hatch into free-living larvae that crawl up plants and are eaten along with the forage, thus reinfecting the animal. Most of the larvae are found within six inches of the ground, so animals grazing the most desirable, short, highly nutritious forage will ingest more parasites. Control of GIN is increasingly difficult because many parasites have developed resistance to available dewormers. Production and mortality losses from GIN are especially severe for goats, which preferentially avoid infection by browsing high above the ground and therefore have very poor genetic tolerance of the GIN when grazing conventional pastures.

The ideal forage species for our purpose has the traditional positive traits of good yield and nutritive value, plus a beneficial effect on animal health and GIN control. Forages can affect GIN control either indirectly or directly. Any forage can impact animal tolerance to GIN through indirect means, simply by providing a superior source of nutrients that strengthen the animals' immune system and enables them to better resist the parasite attack. In addition, some forages directly inhibit some phase of the life cycle of the worms. Direct inhibition can be biochemical or mechanical. Biochemical inhibition occurs when the plant contains bioactive compounds that are toxic to the parasitic worm. Mechanical inhibition occurs when the structure of the plant canopy reduces the number of infective larvae in the grazed zone.

Recent research projects at AFSRC have evaluated indirect means of GIN control such as grazing legumes to improve protein nutrition of finishing goat kids and grass-finishing lambs on stockpiled prairie bromegrass. Projects studying direct GIN control include soil fertility management to improve bioactive chemical concentration in forage chicory, an evaluation of tannin-containing forage species for Appalachia, and evaluation of potential bioactivity in forage brassicas.

Legume Pastures for Meat Goats

A recently completed study at AFSRC compared meat goat kid performance on grass (orchardgrass, *Dactylis glomerata*) versus legume (alfalfa, *Medicago sativa*, or red clover, *Trifolium pratense*) pastures (see Turner et al., in this proceedings). Legumes are highly valued in agricultural systems because they obtain N from the air and thus do not require N fertilizer. High fertilizer prices underscore the importance of this contribution. In addition to fertilizer benefits, legume forages are also highly nutritious pasture



components that are readily eaten by sheep and goats. The high protein content of legumes is considered to be especially beneficial to improving livestock immune system function and tolerance to GIN. Many legumes are easily added to existing pastures using frost-seeding, which is broadcasting seed over pastures in February when the soil surface is freezing at night and thawing in daytime. The freeze-thaw action buries the seed, which germinates later when temperatures are warm.

Alfalfa was chosen for this experiment because of its outstanding overall yield and nutrition potential, whereas red clover was chosen because it contains compounds that protect proteins from degradation in the rumen and thus allows animals to digest an increased amount of the high quality plant proteins in the forage. Alfalfa pastures at AFSRC persisted for four years under combined haying and rotational grazing management and produced better animal gains than orchardgrass (0.17 versus 0.10 lb/day, Turner et al., 2009). This occurred even though orchardgrass produced more forage mass in most years, with nutritive value exceeding minimum requirements for growing goats. Alfalfa is a high maintenance pasture forage that cannot be frost-seeded. It requires deep soils with good drainage, soil pH of 6.5, intensive site preparation for planting, relatively high annual applications of P, K, and B, and good insect pest management for best performance. Alfalfa regrows better from the crown than from stem nodes. Because animals may refuse to eat alfalfa stems, alfalfa productivity will be improved if stems are removed by clipping paddocks after grazing. Kids grazing pure stands of red clover in the first year of the study had weight gains comparable to kids grazing alfalfa, but red clover proved difficult to maintain as a pure stand after the first year. It may be better suited as a component of a grass/clover mixture.

Stockpiled Prairie Bromegrass for Grass-finishing Lambs

Prairie brome (*Bromus catharticus*, synonym *B. willdenowii*) is a high quality, palatable South American species that attracted much attention for grazing in the USA upon the introduction of ‘Grasslands Matua[1]’ from New Zealand in the 1980s. Matua lacks persistence under USA growing conditions, but new varieties were developed with cold

[1] Company and trade names are used for the convenience of the reader and do not imply endorsement by USDA over comparable products.

and powdery mildew tolerance better adapted to the USA. At AFSRC, these new varieties 'Dixon' and 'Lakota,' have produced total annual forage yields of up to 7400 lb/acre (Belesky et al., 2006). Dixon has had better mildew tolerance and productivity than Lakota at AFSRC; unfortunately, most US seed distributors currently carry only Lakota. A risk of severe winterkill still exists even with the improved cultivars; stands were lost in one winter out of seven at AFSRC.

One of the strengths of prairie brome is its excellent productivity and nutritional value in fall of the year when many other forages are declining. This could make it useful for finishing lambs or kids on pasture. We evaluated Dixon for fall grass-finishing of lambs in 2006 and 2007 (Cassida et al., 2009). Dixon was stockpiled for about 60 days each year beginning on Aug. 1 and grazed for 24 days beginning in late September. Polypay-cross ewe lambs were strip-grazed at stocking densities budgeted to use 50% ("take half, leave half) or 75% of the available grass. Under this forage budget, the average stockpiled forage mass of 4000 lb/acre allowed stocking rates of 30 and 47 lambs/acre for the 50 and 75% utilization treatments. Weight gain of lambs was excellent on both treatments (Table 1). The 75 % forage utilization treatment reduced final lamb weight (92.4 vs. 90.6 lb for 50 vs. 75%, respectively) and ADG (0.58 vs. 0.48 lb/d), but improved number of animal grazing days (121 vs. 187 d/acre) and gain per unit pasture area (172 vs. 225 lb/acre). Lamb performance was greater than previously-reported gains for lambs fall-grazed on orchardgrass-white clover pastures at our location and were comparable to those expected of grain-fed lambs. Fall grazing treatments had no effect on hay yields or nutritive value of prairie brome in the following spring. The outstanding performance of animals on this grass can make it worthwhile to take the risk of mildew and winterkill. Research efforts at AFSRC continue to address fine-tuning management of this grass for small ruminants.

Table 1. Performance of ewe lambs, forage mass, and forage nutritive composition of stockpiled Dixon prairie brome at grazing intensities set to utilize 50 (GI50) and 75% (GI75) of forage mass in autumn 2006 and 2007.

	Grazing Intensity				
	GI50	SE	GI75	SE	*P* <
Initial lamb weight, kg	35.9	0.47	35.9	0.48	0.98
Final lamb weight, kg	42.3	0.53	41.2	0.50	***
Gain per lamb, kg	6.5	0.21	5.3	0.24	***
ADG^{z}, g/d	264	8.6	216	10.0	***
Animal grazing days/ha	736	88.2	1143	116.5	**
Gain per hectare, kg	193	10.5	253	17.8	***
Forage mass, Mg/ha	4.32	0.266	4.57	0.183	0.12
<u>Nutritive value</u>					
CP, %	19.4	0.62	19.0	0.69	0.66
NDF, %	58.8	0.65	59.4	0.55	0.60
ADF,%	32.0	0.52	32.7	0..39	0.14
TNC, %	8.6	0.57	9.5	0.64	0.14
IVTD, %	74.1	0.81	76.0	0.82	0.12

*,**,*** Significantly different at $P < 0.05$, 0.01, and 0.001, respectively.

^{z}ADG=average daily gain, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, TNC = total nonstructural carbohydrates, IVTD = in vitro true digestibility.

Influencing Bioactive Components of Forage Chicory through Phosphorus Fertility

Chicory (*Cichorium intybus*) is a perennial herbaceous forb whose naturalized blue flowers are a familiar site along roadsides in summer. Improved varieties developed specifically for forage production have much greater leaf yield than the naturalized type. It is tolerant of soil acidity down to 5.5, poor fertility, and drought. In West Virginia and Pennsylvania trials, chicory has produced total yields of 4900 to 7100 lb/acre/year, split across three to six harvests per season. Nutritive value of the forage is comparable to legumes. Chicory contains several different secondary plant compounds (sesquiterpene lactones, cichoriin, and condensed tannins) that negatively affect GIN (see Foster et al. in this Proceedings for details about secondary compounds in chicory). Unfortunately sesquiterpene lactones are very bitter and may reduce palatability of the forage. Sheep refused to eat specific chicory cultivars when sesquiterpene lactone concentrations were too high (Foster et al., 2002), but Boer-cross goat kids did not discriminate among cultivars in a palatability test. This supports the idea that goats are more tolerant of bitter flavors than sheep and may indicate that goats will be more accepting of pasture plants with beneficial biochemical components. From a production standpoint, phosphorus (P) fertilization improved annual dry matter yield of forage chicory by 27% when soil test P was less than 47 lb/acre (Fig. 1, Cassida et al., 2009). Only 'Puna' chicory maintained acceptable productivity through the third year of the study (Fig. 2) and P fertility did not improve practical stand life.

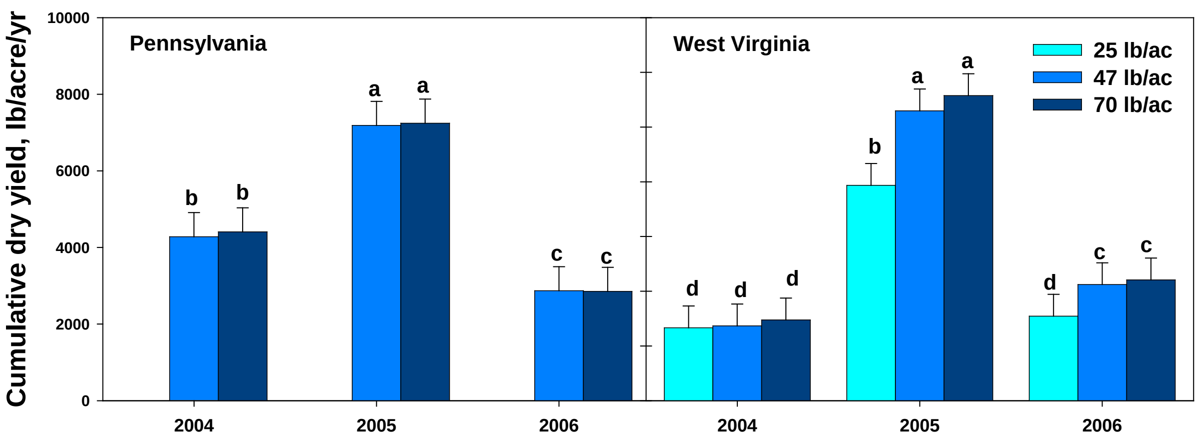


Fig. 1. Cumulative annual dry matter yield of chicory grown with three levels of available soil P for three years in Pennsylvania and West Virginia. Bars with different letters within sites are different (P < 0.05).

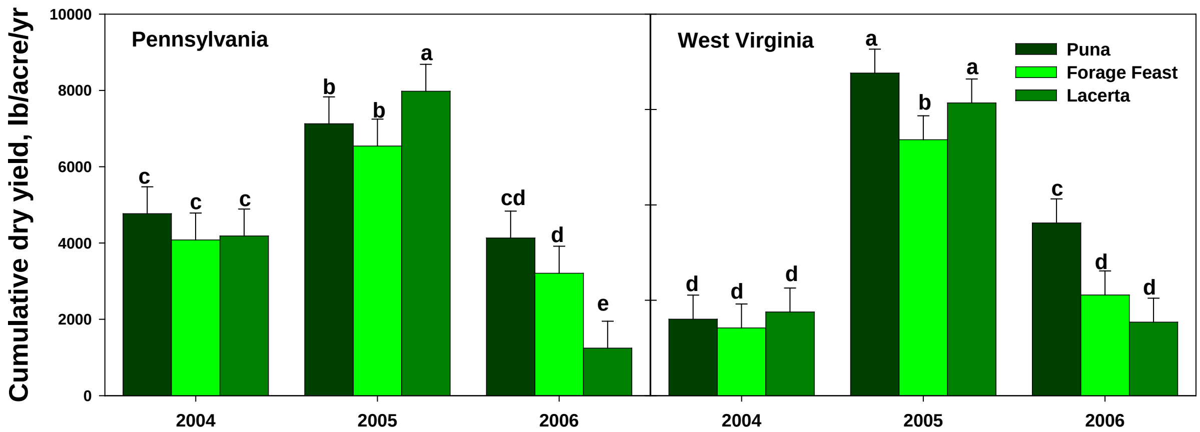


Fig. 2. Cumulative annual dry matter yield of three chicory cultivars grown for three years in Pennsylvania and West Virginia. Bars with different letters within sites are different ($P < 0.05$).

Condensed Tannins for GIN Control

One of the most promising classes of bioactive compound for GIN control is condensed tannin (CT), which are found in many broad-leaf plants. Condensed tannins in pasture and hay forages can reduce fecal egg count (FEC) in sheep and goats (Lange et al., 2006; Shaik et al., 2006) and have additional benefits in that they prevent bloat and improve protein utilization by ruminants. However, CT are not palatable and can have negative effects on intake and performance if present in too great a concentration. The range of 2.5 to 4.5% CT is considered beneficial for GIN control (Min et al., 2003).

Sericea lespedeza (*Lespedeza cuneata*) has received most of the current attention as a CT-containing forage for GIN control. Because sericea lespedeza easily reseeds itself, is not palatable to cattle, and can crowd other plant species out of mixtures, it is classified as a noxious weed in Kansas and Colorado, where grazing with goats is often suggested as a control method! Despite its invasive reputation, sericea lespedeza can be difficult to grow in Appalachia. It has weak seedlings that are not competitive with weeds on fertile ground, takes a year or more to establish, regrows slowly after grazing/cutting, and is not tolerant to continuous stocking. It is an extremely frost-sensitive and has a relatively short growing season in most of the Appalachian region. The beneficial effect of CT on

GIN control disappears within a few days of removing the CT from the diet; therefore, sericea lespedeza may have limited usefulness as a pasture in Appalachia because a consistent supply of lespedeza may not be available when GIN burdens in livestock are high. Fortunately lespedeza is also effective against GIN when fed as hay, which has the advantage of being storable so that it can be fed at any time of year where GIN control is needed. Therefore, ongoing research with sericea lespedeza at AFSRC is focusing on its use as a hay crop.

Birdsfoot trefoil (*Lotus corniculatus*) is another CT-containing legume forage. It is a cool-season reseeding perennial that already has a long history of use in pastures because of its ability to tolerate wetter soils, poorer fertility, and lower soil pH than most other legumes (Ball et al., 1996). This cold-tolerant legume has a long growing season and is better adapted to Appalachia than is sericea lespedeza. The primary reason that trefoil is not already used more widely is that it is notoriously slow and risky to establish. It can be added to existing pastures by frost-seeding, but results may take a year or more to become evident. Birdsfoot trefoil has been shown to help control GIN of sheep in New Zealand, but has not been evaluated for this purpose in the USA. Overall CT levels in trefoil are much less than lespedeza. In a cultivar comparison at AFSRC, the most readily available commercial trefoil cultivar, 'Norcen,' had the lowest CT concentration (1.3 %) and was below the range considered beneficial for GIN control. Cultivars with greater CT concentrations than Norcen do exist, but seed availability is limiting. It is also not clear whether the GIN control effects of birdsfoot trefoil are due to CT itself, to disruption of worm migration up forage stems, or to better nutrition of grazing animals.

Forage Brassicas for Small Ruminants in Appalachia

Forage brassicas (*Brassica* spp.) are annual crops that include turnips (grown for both tops and roots), swedes (also called rutabagas, and grown for both tops and roots), and forage rape and kale (grown for tops only). The foremost advantage of forage brassicas is their nearly unmatched cold tolerance coupled with extremely high forage quality, which makes them very well suited for fall finishing of lambs. Lamb gains up to 0.72 lb/day have been reported for turnip-grazed lambs in WV (Reid et al., 1994).

Forage brassicas usually yield more under cultivation, but this requires land with a suitable slope, which is at a premium in Appalachia. No-till planting can be used, but requires sod suppression with herbicides or heavy grazing because seedlings are not vigorous. Sod suppression by heavy grazing usually doesn't last long enough to allow the brassica seedlings to establish. Under cultivation, 'Tyfon' turnip yielded approximately 3100 lb/acre at AFSRC (Belesky et al., 2006). Under no-till seeding, forage rape was more productive than turnip (3941 vs. 2731 lb/acre; Cassida et al., 2005) when establishment was successful, but no-till planting failed to produce acceptable stands of turnip 37% of the time. In addition, sod control with glyphosate herbicide (Roundup) reduced hay yield of the original orchardgrass pasture in the following year by up to 42%. Therefore we do not recommend that sod suppression with glyphosate be used to establish brassicas on productive pastures, but it can be a good choice as the first step in renovating a declining pasture because the brassicas leave a soil surface perfect for frost-seeding or no-tilling of grasses and legumes the following spring.

Brassica species contain several types of secondary compound. One type, glucosinolates, has attracted recent attention for biofumigant activity against plant-parasitic soil nematodes, leading us to hypothesize whether glucosinolates might also inhibit GIN. Another brassica secondary compound, S-methyl cysteine sulfoxide (SMCO), is undesirable because it sometimes causes anemia in grazing animals (REF), and we hypothesized this could potentially make anemia worse in parasitized animals. In a pen-feeding study at AFSRC, goat kids artificially infected with *H. contortus* gained more weight when fed a turnip-based diet than when fed a hay-based diet of equivalent nutritive value, and the turnip diet did not make parasite-induced anemia worse. However, our research to date has detected no direct inhibitory effect of turnip or rape forage on *H. contortus* in standard laboratory assays and more work remains to be done before we can conclude that how forage brassicas fit into GIN control systems.

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Plant Constituents: Opportunities to Control *Haemonchus contortus*

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Abstract

The rapidly diminishing effectiveness of commercial dewormers against *Haemonchus contortus* (barberpole worm) is a serious threat to the sheep and goat industries. In the absence of new anthelmintic drugs, phytochemicals are considered the most promising supplemental approaches for control of this economically important gastrointestinal parasite. Condensed tannins in herbaceous forages and sesquiterpene lactones isolated from forage chicory (*Cichorium intybus* L.) have exhibited anthelmintic activities. Use of tanniferous legumes for parasite control in temperate climates is the target of numerous investigations, but achievement of this objective is complicated by establishment problems. On the other hand, chicory is relatively easy to establish in temperate environments. Quantitative analyses of the sesquiterpene lactones in chicory herbage and *in vitro* parasitology assays suggest that cultivars with a high sesquiterpene

lactone concentration and a sesquiterpene lactone composition dominated by 8-deoxylactucin may be the best choices for bioactive pastures for *H. contortus* control. *In vitro* and controlled-environment studies with emulsions of oils extracted from orange peels suggest that orange terpenes might be used successfully to disrupt the life cycle of *H. contortus*. They provide the foundation for field and animal studies that are necessary before on-farm use of orange oils for *H. contortus* control can be considered.

***Haemonchus contortus*: A problem with limited solutions**

The gastrointestinal parasite, *Haemonchus contortus* (barberpole worm), has become a major concern for sheep and goat producers worldwide. This worm is particularly pathogenic because, once established in the abomasum (fourth compartment of the ruminant stomach), it aggressively feeds on the blood of the infected ruminant, causing both production losses and mortality. Prevailing practices for *H. contortus* control are based on the strategic use of pharmaceutical dewormers (anthelmintics). Heavy reliance on a limited number of dewormers has resulted in resistance of *H. contortus* to all three classes of available broad-spectrum anthelmintic drugs (benzimidazoles, nicotinics, and macrolides) (Jackson and Coop, 2000; Kaplan, 2004). Multi-drug resistance is now prevalent, and in some locations, the parasite is resistant to all of the synthetic dewormers. A new class of anthelmintic compounds (amino-acetonitrile derivatives) that has a different mode of action has been identified, and a dewormer from this activity class will soon be available in New Zealand for use in sheep (Kaminsky et al., 2008a,b). Approval from the U.S. Food and Drug Administration will be required before this dewormer can be marketed in the U.S. The approval process is intensive and time consuming, meaning that it could be years before this product or other new dewormer might be available to producers here. In the interim, alternative and supplementary approaches for *H. contortus* control are critical to the sustainability of the small ruminant industry. The consensus is that natural products produced by plants offer the greatest opportunities for success in the short term.

Bioactivity of phytochemicals

Plants produce many chemicals that do not participate in their primary life processes. These so-called secondary metabolites are numerous and varied in chemical structure and are involved in complex interactions between plants and the many components of their surroundings. Some of these compounds are important pollination or feeding attractants that promote plant reproduction and dispersal. Others function as antifeedants, protecting plants against herbivorous insects and grazing or browsing animals. Still others help plants form beneficial associations with other organisms, adapt to environmental stresses, resist pathogenic organisms, or fight competing plant species. Many secondary metabolites have medicinal value, and the use of plants and plant extracts for treatment of worms in humans is mentioned frequently in ethnobotanical literature. These facts support the possibility of finding bioactive plants or plant constituents that can suppress free-living forms of *H. contortus* (eggs and first-, second-, and third-stage larvae) in fecal pellets and pastures and infective forms (third- and fourth-stage larvae and adults) in the gastrointestinal tract of small ruminants.

Herbal dewormers

Herbal dewormers, which contain mixtures of plant materials, are available commercially. These products, however, have not proven to be effective against *H. contortus*, when tested in controlled experiments with sheep and goats (A. Zajac, personal communication; Burke et al., 2009).

Tanniferous legumes

Forages that contain chemicals called condensed tannins exhibit beneficial impacts on small ruminants that are infected with *H. contortus*. New Zealand studies have shown that consumption of tanniferous legumes by lambs reduces helminth infestation and improves performance (Niezen et al., 1993; Scales et al., 1995; Waghorn et al., 1995). The mechanisms behind these observations have not been determined, but direct and indirect effects of condensed tannins on viability of nematode eggs, survival or growth of larvae, and/or fecundity of adult worms appear to be involved (Waghorn et al., 1995; Athanasiadou et al., 2000a,b).

Anthelmintic effects of condensed tannins are influenced by the chemical structure and size of the tannin polymers. Diverse structures exist, and plant species vary in tannin composition. Observed effects may therefore reflect contributions of more than one tannin structure. In addition, condensed tannin concentrations vary with plant maturity, tissue type, and environment. The consequence of these chemical variations is that tanniferous plants are not equally effective in controlling *H. contortus*.

Another complicating factor is the limited number of tanniferous forage species, especially ones adapted to temperate climates. In the U.S., research on tanniferous legumes for *H. contortus* control has focused on sericea lespedeza (*Lespedeza cuneata* [Dum.-Cours.] G.Don). Establishment of this plant species in central Appalachia is difficult, and this issue underlies investigations of other native and introduced plant species described elsewhere in these Proceedings.

Secondary metabolites in chicory herbage

Forage chicory is a nutritious, high-yielding, perennial herb that is adapted to temperate climates. It is used in pastures to improve forage availability and nutritive value during summer. Consumption of chicory herbage has been reported to improve performance of small ruminants infected with gastrointestinal parasites (Scales et al., 1995) and reduce the need for pharmaceutical dewormers (Hoskin et al., 1999). Although dietary chicory has sometimes (Scales et al., 1995; Knight et al., 1996; Heckendorn et al., 2007), but not always (Marley et al., 2003b; Athanasiadou et al., 2006), been associated with reduced fecal worm egg numbers, it has consistently been reported to reduce abomasal worm burdens (Scales et al., 1995; Marley et al., 2003b; Tzamaloukas et al., 2005; Heckendorn et al., 2007). Tzamaloukas and coworkers (2005) specifically noted a reduction in the number of male worms. Adverse effects on development or survival of infective larvae in feces from parasitized ruminants that consumed chicory have also been observed (Marley et al., 2003b). Enhanced performance of parasitized small ruminants grazing chicory pastures may be attributed, in part, to the excellent nutritional quality of chicory. Secondary metabolites from several classes of chemicals, including condensed tannins, sesquiterpene lactones, and coumarins, are believed to contribute to the anthelmintic effects of chicory.

The studies mentioned above were conducted with the New Zealand cultivar ‘Grasslands Puna’. Now, more than half a dozen varieties of forage chicory are available commercially. These varieties include Grasslands Puna; two improved cultivars, ‘Puna II’ (marketed in the U.S. as ‘Oasis’) and ‘Choice’, developed in New Zealand from Grasslands Puna; ‘Six Point’, produced from Grassland Puna in the U.S.; ‘Forage Feast’, developed in France from a root-type chicory; and two cultivars from Uruguay, ‘Lacerta’ and ‘La Niña’. As a first step in determining whether one cultivar might be better than another for *H. contortus* control, we have conducted a number of experiments to determine how secondary metabolite composition varies among these cultivars. Herbage for chemical analyses was drawn from controlled environment studies as well as plot studies conducted in West Virginia, Pennsylvania, Ohio, and Mississippi. Plant samples represented a variety of growing conditions, and included initial growth and regrowth harvested throughout multiple growing seasons.

Table 1. Forage chicory cultivars, origins, and relative concentrations of condensed tannins and sesquiterpene lactones.

Cultivar	Origin	Condensed tannin concentration	Sesquiterpene lactone concentration
Grasslands Puna	New Zealand	Low	High
Puna II/Oasis	New Zealand	Low	High
Choice	New Zealand	Low	Low
Six Point	United States	Low	High
Lacerta	Uruguay	Low	Low
La Niña	Uruguay	Low	Low
Forage Feast	France	Low	High

Quantitative results for condensed tannins and sesquiterpene lactones in chicory cultivars are summarized in Table 1. Condensed tannins are present in all cultivars, and the concentration is uniformly low. On the other hand, cultivars can be divided into two groups, based on sesquiterpene lactone concentration. Under the same conditions, Grasslands Puna, Oasis, Six Point, and Forage Feast have higher concentrations of sesquiterpene lactones than Choice, Lacerta, and La Niña. Molan and colleagues (2003) observed reduced motility of infective *H. contortus* larvae that had been exposed to crude sesquiterpene lactones from Grasslands Puna chicory. Our results therefore suggest that cultivars with the higher sesquiterpene lactone concentration would be preferable in bioactive pastures for *H. contortus* control in small ruminants.

Seasonal variations in sesquiterpene lactone concentration in two unrelated chicory cultivars from the high concentration group are illustrated in Table 2. Although concentrations in both Grasslands Puna and Forage Feast fluctuated during the course of the growing season and between growing seasons, there is no apparent advantage of one cultivar over the other at any particular time of the season.

Table 2. Seasonal variations in sesquiterpene lactone concentration in chicory cultivars grown in West Virginia.

Harvest date		Total sesquiterpene lactones, mg/g dry weight	
		Grasslands Puna	Forage Feast
2005	May 31	11.3 ± 3.3	11.2 ± 3.1
	June 21	13.8 ± 3.0	15.9 ± 0.8
	July 12	15.1 ± 2.0	16.1 ± 0.9
	August 16	10.4 ± 3.9	13.3 ± 2.1
	October 3	9.3 ± 1.6	11.7 ± 0.4
2006	June 6	10.4 ± 1.5	12.1 ± 1.5
	July 18	9.7 ± 0.8	10.6 ± 1.4
	September 6	8.4 ± 2.0	8.9 ± 0.9
	October 18	7.4 ± 0.5	8.6 ± 1.3

Chicory leaves contain three sesquiterpene lactones, lactucin, 8-deoxylactucin, and lactucopicrin. Table 3 summarizes the sesquiterpene lactone composition of Grasslands Puna and Forage Feast herbage from three independent studies representing four cultivation sites, multiple years, and multiple harvests during the growing season. The sesquiterpene lactone composition is quite consistent for the individual cultivars; however, major differences between the cultivars exist. In Forage Feast, lactucin represented 40 to 50 % of the total sesquiterpene lactones, approximately twice the fraction it represented in Grasslands Puna; the fraction of 8-deoxylactucin in Forage Feast (15-25%) was approximately half that in Grasslands Puna. Lactucopicrin represented a similar fraction of total sesquiterpene lactones in the two cultivars (30-40%). The anthelmintic potential of the individual compounds is not known. If they are not the same, sesquiterpene lactone composition could be an important aspect of cultivar selection for small ruminant pastures.

Table 3. Sesquiterpene lactone composition of chicory cultivars.

Cultivar	Lactucin, %	8-Deoxylactucin, %	Lactucopicrin, %
Grasslands Puna	21 - 29	33 - 45	33 - 40
Forage Feast	38 - 49	14 - 26	32 - 40

Parasitological studies are needed to determine the anthelmintic efficacy of the individual cultivars. We have prepared sesquiterpene lactone-enriched fractions from both Grasslands Puna and Forage Feast and used fractions containing the same sesquiterpene lactone concentration to investigate their effect on the hatching of *H. contortus* eggs and the motility of infective, third-stage *H. contortus* larvae. We identified a concentration of Grasslands Puna sesquiterpene lactones that inhibited egg hatching by 70%. The same concentration of Forage Feast sesquiterpene lactones was only 25% effective in preventing egg hatching. At concentrations tested to date, no differences in inhibition of larval motility by Forage Feast and Grasslands Puna sesquiterpene lactones have been detected. Although these results are preliminary, they suggest that 8-deoxylactucin may be an important factor in disrupting the life cycle of *H. contortus*. Cultivars that have a high sesquiterpene lactone concentration dominated by 8-deoxylactucin may be especially useful in providing both nutritious forage and *H. contortus* control.

Cichoriin, a coumarin, may be another component in the arsenal of anthelmintic compounds in chicory, but this compound has received little attention to date. We are developing methods to extract and quantify cichoriin. Our goal is to determine how its concentration varies among the chicory cultivars and to demonstrate its anthelmintic potential. The presence of multiple anthelmintic constituents in a plant can impede the development of parasite resistance to the effective compounds.

Orange terpenes

Oils extracted from orange peels contain high concentrations of terpenes. These compounds have antimicrobial activity (Vargas et al., 1999), and preliminary investigations indicated that orange oil emulsions are effective against plant parasitic nematodes (E. Rosskopf, personal communication). Orange terpenes have low oral toxicity and low dermal toxicity when tested on rabbits. The principal constituent of orange oils, d-limonene (90 - 95%), is considered to have moderate and low skin irritancy, respectively, for guinea pigs and rabbits. Orange oils do not contain known reproductive or developmental toxins. Food-grade orange oils are sold commercially and considered to be readily biodegradable. We therefore investigated the potential of these oils to disrupt the *H. contortus* life cycle by assessing the ability of an orange oil emulsion to inhibit hatching of *H. contortus* eggs and to inhibit the motility of infective, third-stage *H. contortus* larvae. The emulsion used in these studies contained orange terpene oil, orange Valencia oil, an emulsifier, water, and hydrogen peroxide.

When *H. contortus* eggs were treated with 1% orange oil emulsion, 45% of the eggs failed to embryonate, and none of the embryonated eggs hatched (Table 4). Inhibition of hatching was dose-related. More eggs embryonated and more hatched following treatments with 0.5% and 0.2% orange oil emulsion, but even treatment with 0.2% orange oil emulsion prevented approximately two thirds of the eggs from hatching. In comparison, eggs subjected to treatment with water hatched. Hatching was completely inhibited by treatment of eggs with the commercial dewormer Ivomec®. [Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.]

Table 4. Inhibition of *H. contortus* egg hatching by an orange oil emulsion (OOE).

Treatment	Embryonated eggs	Non-embryonated eggs	Hatched eggs[z]
	---	%	-----------------------------------
Ivomec	89	11	0
1% OOE	55	45	0
0.5% OOE	68	16	16
0.2% OOE	62	2	36

[z] Calculated from the difference between the number of worms in the negative control (water) and the sum of the embryonated and non-embryonated eggs in the test treatment. Values are means for eight replicates.

Table 5. Inhibition of motility of infective third-stage *H. contortus* larvae by an orange oil emulsion.

OOE concentration	LMI[z]
-------------------%	------------------
10	91.3
7	85.5
5	83.7
3	80.6
1	63.8

[z] Larval migration inhibition.

Larval motility was inhibited by approximately 60% when infective third-stage larvae were exposed to 1% orange oil emulsion (Table 5). Treatment with 10% orange oil emulsion resulted in approximately 90% inhibition. While this assay does not distinguish between dead and inactive larvae, exposure of third-stage larvae to 1 to 10% orange oil emulsion in a pasture could diminish the number of larvae capable of moving into the grazing horizon and thereby diminish the number of infective larvae ingested by grazing livestock. No adverse effects were detected by visual inspection following applications of 2% or 5% orange oil emulsion as a controlled-volume mist to 6-week-old seedlings of four common forage species: alfalfa (*Medicago sativa* L.), red clover (*Trifolium pretense* L.), orchardgrass (*Dactylis glomerata* L.), and chicory. Two days post treatment, only red clover seedlings receiving 10 or 20% orange oil emulsion exhibited leaf damage.

We investigated potential adverse effects of the orange oil emulsion on rumen function using in vitro rumen fermentation procedures. Degradation of representative forage species [orchardgrass (grass), alfalfa (legume), and chicory (forb)] in the presence of the emulsion paralleled that observed with soybean oil when the orange oils and soybean oil were present at a concentration (2%) typically used for dietary supplementation of ruminants.

Our results suggest that orange oil emulsions might be applied to pastures and administered to ruminants to effectively disrupt the life cycle of *H. contortus*. Although the results are encouraging, orange oil emulsions or other products containing orange oils <u>must not</u> be used by producers for *H. contortus* control. Extensive research must be conducted to ensure that experimental materials are safe for livestock and that products derived from animals receiving such experimental materials are safe for consumers. Appropriate doses for the type, size, and condition of the ruminant being treated must be defined. Environmental and ecological impacts of field applications must also be addressed.

Conclusions

The existence of multiple control points in the life cycle of *H. contortus* provides opportunities to identify a variety of plant materials that can be incorporated in a multi-faceted strategy for control of this helminth. Forages that meet nutritive requirements of small ruminants and also contain secondary metabolites with anthelmintic activity are easiest to integrate into sheep and goat production systems because they do not require special preparation or approval procedures. Even though there is still much to be learned about *H. contortus* control using forage species, herbaceous legumes that contain condensed tannins and forage chicory, with its multiple anthelmintic chemicals, are resources that producers can access immediately to help deal with the evolution of parasite resistance to pharmaceutical dewormers. Identification of anthelmintic properties of constituents in non-forage plant materials is an important first step in defining parasite control strategies based on use of dietary supplements. Researchers must exercise extreme care to ensure that research materials are not adopted prematurely by producers. The importance of strict adherence to guidelines for use of pharmaceutical dewormers also cannot be over-emphasized. Using available resources appropriately and applying good forage-livestock management practices can extend the effective life of anthelmintic drugs.

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Potato Bean: Potential Forage/Dietary Supplement for Small Ruminants

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Abstract

Potato bean (*Apios americana* Medikus) is a nitrogen-fixing, perennial, leguminous vine indigenous to the eastern half of the United States. This vine climbs on plants and objects making its foliage accessible to browsing animals. We have observed deer eating potato bean foliage. Both deer and goats are browsing ruminants that eat leaves and twigs of woody plants to obtain nutrients and beneficial secondary metabolites. By browsing elevated herbage, browsers avoid larvae of parasitic nematodes, such as *Haemonchus contortus*, that proliferate on forage near the soil surface. We investigated the yield and nutritional value of potato bean herbage, which is here reported for the first time. Forty Louisiana potato bean accessions were planted unreplicated at the USDA-NRCS Plant Materials Center, Alderson, WV, on May 9, 2006. At harvest on Sep 22, 2006, plot herbage was weighed, oven-dried at 131°F, ground, and sent to Midwest Laboratories, Inc., Omaha, NE, for feed nutrient analysis. Herbage yields of the best accessions ranged from 2.7 to 3.6 tons/acre. Leaves had almost twice as much crude protein (19.7%) as stems (10.8%) but just 1.1% more than the whole plant (18.6%). Whole plant values for CP (18.6%), ADF (32%), NDF (40.7%), TDN (66.1%), NE-M (0.66 Mcal/lb), and NE-G (0.40 Mcal/lb) approximated those of early bloom alfalfa. The nutritional value of potato bean herbage suggest that it could be a useful component in the diet of browsing ruminants; however, slow establishment and growth on upland sites will not meet the needs of small ruminant producers.

Introduction

We investigate native plants that can help meet the nutritive requirements and support the health of meat goats. Potato bean (*Apios americana* Medikus) is a nitrogen-fixing, tuber-producing, bean-bearing, perennial, leguminous vine that is indigenous to the eastern half of the United States, from Maine to Minnesota and Texas to Florida. The plant grows well in permanently moist soils where conventional legumes would have difficulty growing. It is prevalent near bodies of water, in soils with good drainage, periodic floods and/or high water table (Reed and Blackmon 1985). In our fields, we have observed deer browsing potato bean foliage in early fall when other herbage is still abundant. Goats, like deer, are browsing animals that can obtain nutrients and beneficial secondary metabolites from leaves of woody plants, but most tree leaves are unreachable. Potato bean seeks support from surrounding plants, making foliage accessible to browsing animals. By browsing herbage that is elevated, ruminants avoid larvae of parasitic nematodes, such as *Haemonchus contortus*, that proliferate on forage near the soil surface. Our preliminary analysis indicated that potato bean contains condensed tannins, compounds considered helpful for bloating relief and parasitic worm control in ruminants. Cultural, botanical, and nutritional aspects of potato bean have been reported for tubers (Reed and Blackmon 1985, Blackmon and Reynolds 1986, Reynolds et al 1990, Johnson et al 1990, Wilson et al 1990, Juliarni and Hoshikawa 1994a) but not for herbage. In this study, we investigated the yield and nutritional value of potato bean herbage.

Materials and Methods

Forty accessions (provided by W. Blackmon) from potato bean tuber studies conducted in Louisiana were planted unreplicated at the USDA-NRCS Plant Materials Center, Alderson, WV, on May 9, 2006. The planting area was fertilized with 100 lb/acre of 10-10-10 and divided in plots of 3’ x 6’. Two tubers were planted 3’ apart in the middle of each plot. Plots were mulched with a 4”-thick woodchip layer and aerial tissue was supported with a 5’-tall twine trellis. Plots were harvested on September 22, 2006, and herbage yield per plot was recorded. Harvested tissue was oven-dried at 131°F, ground, and sent to Midwest Laboratories, Inc., Omaha, NE, for feed nutrient analysis. Subsamples from three randomly selected plots were separated into leaves and stems and these fractions were also sent for feed nutrient analysis.

Results and Discussion

Herbage yields of potato bean are shown in Table 1. Yields of the best accessions ranged from 2.7 to 3.6 tons/acre for a single, season-end harvest. The best accession (LA-1661) yielded 8 times better than the worst accession (LA-2185). These yields were similar to the national average for alfalfa (3.35 tons/acre) reported by the USDA Agriculture Statistics in 1998. Accession variability (0.4–3.6 ton/acre) could allow progress in yield improvement.

Table 1. Herbage yield of potato bean accessions grown in Alderson, WV, in 2006

Accession	Herbage Yield	
	Lb/plant	tons/acre[a]
LA-1661[b]	1.5	3.6
LA-2190[b]	1.4	3.3
LA-2011[b]	1.3	3.1
LA-0807[b]	1.3	3.1
LA-2183[b]	1.2	3.0
LA-2161[b]	1.1	2.7
Mean[c]	0.8	1.8
Range[c]	0.2–1.5	0.4–3.6

[a] Estimated, based on an area of 9 ft^2/plant
[b] One of six best-yielding accessions
[c] Based on 40 accessions

Nutritive values of potato bean are shown in Table 2. Leaves had almost twice as much crude protein (19.7%) as stems (10.8%) but just 1.1% more than the whole plant (18.6%). Potato bean values for CP (18.6%), ADF (32%), NDF (40.7%), TDN (66.1%), NE-M (0.66 Mcal/lb), and NE-G (0.40 Mcal/lb) approximated those of early bloom alfalfa. The ratio of Ca (2.27%) to P (0.23%) is 9.9:1, higher that the ratio (1.4:1) recommended for goats (National Research Council, 1981). Copper content (23 ppm) is adequate to meet the recommended dose of 20-25 mg/kg diet DM (National Research Council, 2006). Zinc content (39 ppm) also is adequate; minimum requirements are set at 10 ppm (National Research Council, 1981). Potato bean has acceptable protein, digestibility, and energy values for small ruminant production; however, cultivation would be limited to waterlogged areas where pasturing may create foot disease problems for animals.

Table 2. Nutritive value of potato bean herbage[a]

	Leaves[c]		Stems[c]		Whole plant[d]		
Components[b]	Mean	SD	Mean	SD	Mean	SD	Alfalfa[e]
CP (%)	19.7	± 1.6	10.8	± 1.0	18.6	± 1.8	18
ADF (%)	30.4	± 0.4	43.0	± 2.8	32.0	± 3.4	35
NDF (%)	41.0	± 2.4	53.0	± 1.7	40.7	± 2.3	47
TDN (%)	66.8	± 0.1	62.9	± 0.9	66.1	± 3.8	60
NE-L (Mcal/lb)	0.69	± 0	0.65	± 0.01	0.68	± 0.04	
NE-M (Mcal/lb)	0.67	± 0	0.62	± 0.01	0.66	± 0.05	0.59
NE-G (Mcal/lb)	0.40	± 0	0.35	± 0.01	0.40	± 0.04	0.30
S (%)	0.19	± 0.02	0.10	± 0.01	0.18	± 0.02	0.30
P (%)	0.21	± 0.03	0.17	± 0.02	0.23	± 0.02	0.25
K (%)	1.52	± 0.30	1.17	± 0.13	1.55	± 0.17	2.30
Mg (%)	0.36	± 0.16	0.33	± 0.04	0.35	± 0.06	
Ca (%)	2.06	± 0.57	2.82	± 0.02	2.27	± 0.34	1.40
Na (%)	< 0.01		< 0.01		< 0.01		
Fe (ppm)	480	± 152	115	± 54	548	± 326	
Mn (ppm)	308	± 72	150	± 63	353	± 123	
Cu (ppm)	6	± 1	5	± 1	23	± 19	
Zn (ppm)	22	± 1	28	± 7	39	± 54	18
RFV	148	± 8	97	± 4	147	± 12	

[a] Means and standard deviations (SD) for herbage produced in Alderson, WV, in 2006 are reported on a dry matter basis.
[b] CP = Crude Protein, ADF = Acid Detergent Fiber, NDF = Neutral Detergent Fiber, TDN = Total Digestible Nutrients, NE-L = Net Energy for Lactation, NE-M = Net Energy for Maintenance, NE-G = Net Energy for Gain, RFV = Relative Feed Value.
[c] Data from three random accessions
[d] Data from 33 accessions
[e] Early bloom; Stanton and LeValley, 2006

Conclusions

The nutritional values (protein, digestibility, energy) of potato bean herbage suggest that it could be a useful component in the diet of browsing ruminant livestock. However, due to slow establishment and growth on upland sites potato bean will not meet the needs of small ruminant producers. Accession variability could allow progress in yield improvement.

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Artemisia Species in Small Ruminant Production: their Potential Antioxidant and Anthelmintic Effects.

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Abstract

Although *Artemisia* species (spp.) are rich source of terpenes, antioxidant phenolics and flavonoids, among other biologically-active compounds, only in the past 8-10 years the genus Artemisia has been investigated for its anthelmintic and antioxidant compounds. *Artemisia annua* is a notable exception due to the production of the antimalarial compound artemisinin. These compounds can help parasitized animals to neutralize free radicals that form in their blood, boost their immune system, and help them fight gastrointestinal parasites. This manuscript will present current results on the antioxidant activity of *Artemisia* species, and focus on the genus as a potential source of antioxidant and anthelmintic compounds. Some *Artemisia* spp. had higher antioxidant capacity than conventional forages with some, e.g. *A. annua*, being a good source of minerals, protein, and antioxidants, with negligible amounts of anti-nutritional compounds. Although the anthelmintic activity of artemisinin-related drugs, dry leaves, and alcoholic extracts of *Artemisia* spp. encompass *Schistosoma*, *Fasciola*, *Trypanosoma*, *Eimeria* (coccidia), *Trichostrongylus*, and *Haemonchus*, not all *Artemisia* spp. are effective anthelmintic sources.

Introduction

The genus Artemisia belongs to the family Compositae (Asteraceae) and has over 300 species spread worldwide. Plants from this family are a rich source of sesquiterpene lactones, a class of natural compounds with several proved medicinal effects, including anthelmintic effect. *Artemisia annua* (annual wormwood) has been given the most attention in the past 36 years due to the pharmacological use of artemisinin (the main sesquiterpene produced by the plant) as an antimalarial recommended by the World

Health Organization to treat quinine-resistant malaria in over 50 countries in Africa, Asia, and South America. Artemisinin's second most reported use is as an anti-cancer drug (Efferth et al., 2001; Lai and Singh, 2006). In the past 8-10 years, new medicinal benefits were reported for several *Artemisia* species (spp.) due to the anti-parasitic effects of artemisinin-based compounds and the high antioxidant capacity of crude extracts of some plants of this genus. Besides artemisinin, *Artemisia* spp. are rich sources of sesquiterpene lactones and antioxidant compounds (flavonoids, phenolic acids, etc.) with potential benefits to human and animal health. The antioxidant capacities of the crude extracts of some of these plants are shown in Figure 1 and Table 1.

Current published research shows that artemisinin drugs are effective against *Leishmania*, *Trypanosoma* , and some viruses that affect humans. In animals, the antiparasitic activity of *Artemisia* spp. and artemisinin applies to several parasitic organisms including *Fasciola*, *Eimeria* (coccidia), *Trichostrongylus*, and *Haemonchus* (Table 2).

Gastrointestinal nematodes (GIN) represent a major economic hurdle in ruminant systems, and anthelmintics are estimated to account for 53% of the total costs of veterinary drugs worldwide (Diaz Lira et al., 2008). *Haemonchus contortus*, a GIN of the abomasum, leads in animal losses and is fast becoming multi-drug resistant in several regions of the world. The focus of our research group at the Agricultural Research Service (ARS), USDA, is to find alternative plants that, when fed as forage or forage supplements, have the potential to improve the health of small ruminants in grazing systems. These compounds can work as anthelmintics, directly (affecting larval establishment, larval motility, mortality, decreasing fecal egg output, impairing worm development, and decreasing egg hatchability from feces) or indirectly (balancing antioxidant blood levels, improving the nutritional status, and boosting the immune system of parasitized animals fed these plant materials). Although it is unlikely that this natural approach can totally substitute synthetic anthelmintics, it could reduce their use, make them more effective, and improve meat quality and acceptability by the growing number of consumers demanding organic, kosher, and halal products.

Condensed tannins (CT) are currently the most studied natural class of compounds for their nutritional value (increase in protein uptake) and for reducing fecal egg counts

(FEC) in ruminants infected with GIN. However, recent publications have shown that CT from *Salix* sp. (willow) reduced FEC of *Nematodirus* and *Trychostrongylus*, but increased FEC of *Haemonchus contortus* in sheep (Diaz Lira et al., 2008) and that *Albizia anthelmintica*, with recognized anthelmintic activity and high tannin content, reduced FEC in sheep from 77-90% (Gradé & Longok 200, by Gradé et al. 2008) against mixed nematode infection, but only from 19-34% against *Haemonchus*-only infections (Gradé et al., 2008). These results strongly suggest that the research on natural anthelmintics need to expand beyond CT.

Artemisia species have negligible amounts of tannins, but are rich sources of sesquiterpene lactones and flavonoids that have reported anthelmintic activity. For instance, santonin isolated from *Artemisia* spp. was used to treat intestinal worms before the advent of synthetic anthelmintics, and has recently been used as a reference anthelmintic for in vitro studies. Artemisinin, isolated from *A. annua*, is the raw material for the most potent antimalarial after quinine and has anthelmintic activity against trematodes such as *Schistosoma* in mice, coccidia (*Eimeria*) in chicken, *Fasciola* in sheep, and *Chlonorchis* in rats (Table 2). Other artemisias (Table 2) had anthelmintic effects in vitro or in vivo against several nematodes, including *Haemonchus*, but the active compound (s) was (were) not identified. Regarding "active compound(s)", Kraft and collaborators (2003, cited by Pillay et al., 2008) reported that *Artemisia afra* had antimalarial activity against both sensitive and chloroquine-resistant *Plasmodium falciparum* in vitro, but if the crude extract was fractionated to separate flavonoids and sesquiterpene lactones, the isolated compounds never had the same remarkable activity as the whole crude extract. The authors concluded that the antimalarial activity was due to the synergistic effect of several compounds contained in the crude extract. Some of the artemisias (*annua*, *afra*, and *absinthium*) with antimalarial activity have also anthelmintic activity (table 2).

Anthelmintic studies with the main active compound (artemisinin or related drugs) of *A. annua*, at oral doses of 200 mg/kg were effective against *Schistossoma*, but oral doses of 10 mg/kg, once a day for a week, and 80 mg/kg were ineffective against *Haemonchus*-infected goats (Turner and Ferreira, 2005) and *Fasciola* in sheep (Keiser et al., 2008), respectively, while one single intra-muscular (i.m.) dose of 160 mg/kg reduced *Fasciola* eggs in 65% and the worm burden in 91%, and 80 mg/kg (i.m.) reduced worm burden in 65% (Keiser et al., 2008). These results suggest that: 1) artemisinin is not as effective as its derived drugs such as artemether; 2) the dose of 10 mg/kg used in goats was too low to be effective; 3) the oral route, although more convenient, is not as effective as the i.m. route; 4) artemisinin might not be effective against *Haemonchus* but should be tested against other GIN of ruminants, such as *Eimeria* and *Fasciola*.

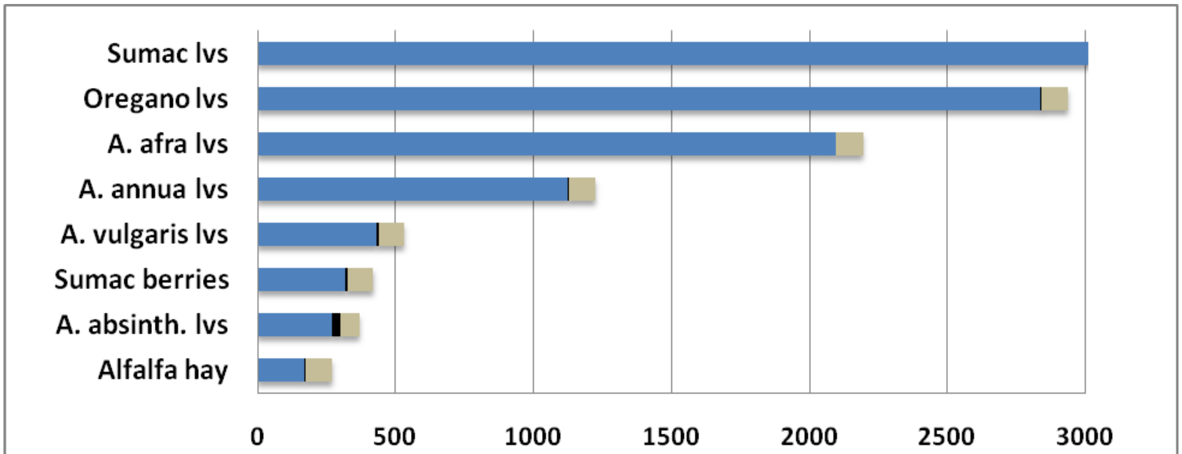
Our recent study showed that artemisinin is fairly stable in rumen fluid at both neutral (75% recovery) and acidic pH (95% recovery) after incubation at 39 ºC for 24 hours, and that artemisinin orally fed to goats at 33 mg/kg was absorbed, transferred to the blood, and metabolized to dihydroartemisinin. Finally, a high concentration of artemisinin was found in goat feces 24 hours after oral intake (Ferreira and Gonzalez, 2008). These results are the first to indicate that artemisinin resists the rumen environment, is metabolized by goats to the active compound dihydroartemisinin, and thus could be useful to treat coccidiosis and fasciolosis in goats and sheep. However, it remains to be tested if the presence of artemisinin in feces will reduce *Haemonchus* egg hatching, thus reducing pasture infection. *Artemisia annua* and artemisinin uses for the livestock industry are currently in expansion, based on current reports of the anti-protozoal, anti-bacterial and antioxidant activities of the plant, its extracts, and its essential oil. Some animal parasites effectively controlled with *A. annua*, its essential oil, and artemisinin include *Babesia* (Kumar et al., 2003), *Eimeria* or coccidiosis (Allen et al., 1997; Arab et al., 2006; Brisibe et al., 2008), the trematodal blood fluke *Schistosoma* spp. (Lescano et al., 2004; Xiao et al., 2000), and bacteria (Juteau et al., 2002). In a recent collaborative study with African, Brazilian, and USDA-ARS colleagues, different tissues of *A. annua* were analyzed for its potential use in animal feed and scored high values for crude protein, antioxidant capacity (Table 1) and as source of amino acids, with negligible amounts of anti-nutritive components such as phytates and oxalates (Brisibe et al., 2009).

This manuscript highlights the antioxidant and anthelmintic potential of several species of *Artemisia* published previously, and presents results from our ongoing research.

Antioxidant activity

Artemisia spp. have high content of flavonoid and phenolic compounds that are associated with their high antioxidant capacity. *Artemisia* spp. can score 50% or more of the total antioxidant capacity (TAC) measured by the oxygen radical absorbance capacity (ORAC) test and found in oregano (Table 1), the herb with the highest known ORAC value. There is indication that the flavonoids and phenolic acids found in leaves and crude alcoholic extracts have medicinal effects on their own, such as antioxidant and anti-cancer, or have synergistic effects with other medicinal compounds present in the plant, increasing their absorption, pharmacological activity, and permanence in the human or animal subject consuming the plant or extract (Blanke et al., 2008). Recently, plant materials with high antioxidant capacity such as *Artemisia afra* tops and grape seeds were found to attenuate coccidian infection in chickens and even increased the body weight of infected birds, similar to chickens in a control diet (Naidoo et al., 2008). *A. annua* leaves (Zheng and Wang, 2001) and crude extracts have been reported to be a good source of antioxidants (Cai et al., 2004), being among the four medicinal plants with the highest ORAC level among other Chinese medicinal plants (Zheng and Wang, 2001). This high antioxidant capacity was attributed to the high content and diversity of its leaf flavonoids, including C-glycosyl flavonoids as a possible component of the antioxidant and antiviral activity (Han et al., 2008). Flavonoids have been reported to be responsible for more of the antioxidant activity of leafy vegetables and herbs than vitamin E, C, or glutathione (Cao et al., 1996). Although the antimalarial activity of *A. annua* is mostly attributed to artemisinin, flavonoids from whole plant extracts also had antimalarial activity (Liu et al., 1992). Although it has been known that *Artemisia* spp. are rich in flavonoids, our literature search has resulted in less than 15 manuscripts focusing on the antioxidant capacity of *Artemisia* spp., and published from 2001 to 2009. One of those was the result of an international collaborative work on the nutritional and antioxidant characteristics of *A. annua* (Brisibe et al., 2009), with partial results presented in Table 1.

On Figure 1, we present results of antioxidant activity (ORAC) of some *Artemisia* spp., compared to other plants, and performed in our laboratory and elsewhere. These artemisia species, cultivated in West Virginia, showed that *A. afra* and *A. annua* had the highest ORAC values of the tested artemisias with total antioxidant capacities of 2,095 and 1,125 µmol TE/g, respectively. The ORAC values for oregano reported here (2,838 µmol TE/g) are about 1,000 ORAC units higher than the ones previously reported in the literature (ranging from 1,500-1,800 µmol TE/g). This oregano was cultivated in our greenhouses, harvested monthly, oven dried at 45 ºC, and stored at room temperature for over two years before analysis.



	Alfalfa hay	A. absinth. lvs	Sumac berries	A. vulgaris lvs	A. annua lvs	A. afra lvs	Oregano lvs	Sumac lvs
TAC (Hydro+Lipo)	171.1	270.4	320.2	431.4	1124.6	2095	2838.3	5338.7
% Lipo of TAC	2.98	32.29	5.68	8.02	3.08	2.05	0.64	1.90
% Hydro of TAC	97.02	67.71	94.32	91.98	96.92	97.95	99.36	98.10

Figure 1. Total antioxidant capacity (TAC) of leaves (lvs), berries, and hay of some atemisias determined by the oxygen radical absorbance capacity (ORAC) and compared to other plants and forages. The TAC (dark gray) was separated into percentages of its hydrophilic (light gray) and lipophilic (black) fractions. The TAC of sumac leaves is off the chart.

Artemisia vulgaris presented an ORAC value (TAC) of 431, equivalent to sericea lespedeza and forage grasses, such as switchgrass (Table 2), but this was a variegated, ornamental, cultivar and the wild type needs to be tested. It is interesting to notice that staghorn sumac leaves scored over 5,000 and could be a valuable antioxidant source to use as a feed additive because it has over 10 times the ORAC value of lespedeza, forage grasses, and some artemisias. It is also worth noticing that the percent of the TAC pertaining to the lipophilic fraction was less than 10%, except for *A. absinthium*, confirming that vitamins A, C, D, and E (all lipophilic) are only minor components of the plant antioxidant activity. The hydrophilic fraction represented most of the TAC. This fraction contains the flavonoids, phenolics acids, and tannins produced by the plants. This is also indicated by the fact that both aqueous and ethanolic extracts of a Brazilian and of a Chinese *A. annua* had hydrophilic ORAC values of 2,123, 2,535 and 1,960 µmol TE/g, respectively (Table 1). These ORAC values, added to the total phenolics data (Table 1) indicate that artemisia leaves and crude extracts are a valuable source of antioxidants to animals, compared to lespedeza and trefoil (Table 1). The fact that the ORAC values for the Brazilian *A. annua* were higher than for the Chinese indicate that the Brazilian cultivar is a higher source of antioxidants than the Chinese, which agrees with a recent study (Bilia et al., 2006) that states that the Brazilian cultivar had a higher content of flavonoids than the Chinese cultivar. Interestingly, *A. annua* leaf ORAC of a cloned Swiss cultivar that was freeze-dried and compared to the oven-dried (40 ºC) leaves indicated that there was no statistical difference in total antioxidant activity (TAC), although the lipophilic ORAC values were lower for the oven-dried samples (Table 1). These results indicate that lipophilic vitamins (A, C, D, and E) might have degraded during oven drying, again confirming reports that flavonoids have more antioxidant power than vitamins (Cao et al., 1996). Thus, our results agree with those of others in that the bulk of the antioxidant activity represented in the ORAC-TAC (ORAC-H + ORAC-L) is mostly present in the hydrophilic (ORAC-L) fraction with the lipophilic fraction (ORAC-L) representing less than 10% of the TAC. Besides the high antioxidant capacity of *A. annua*, recent work with our African collaborators has established the plant as a good source of amino acids (18%), crude protein (27%), minerals (mainly potassium and calcium in the leaves), while low in anti-nutritive components such as phytates and oxalates (Brisibe et al., 2009). High protein content translates into important essential amino acids needed for the development of healthy bones, muscles, skin and blood, while potassium maintains water balance in the body as an electrolyte, participates in the transmission of nerve impulses to muscles, and in the maintenance of normal blood

Table 1. Antioxidant capacity of *Artemisia annua* and a few conventional forages expressed in oxygen radical absorbance capacity (ORAC) for the hydrophilic (Hydro) and lipophilic (Lipo) fractions and as total antioxidant capacity (TAC) in µmol of Trolox equivalents (TE) per gram of dry weight (DW). Total phenolics of *Artemisia annua* are expressed in mg of gallic acid equivalent per gram of dry weight, adapted from (Brisibe et al., 2009). Oregano ORAC is given for comparison, as the highest ORAC value reported for an herb.[z]

PLANT SOURCE	**ORAC-HYDRO**	**ORAC-LIPO**	**(LIPO X 100)) TAC**	**ORAC-TAC**	**TOTAL PHENOLICS**
MEDICINALS	(µmol TE/g DW)	(µmol TE/g DW)	(%)	(µmol TE/g DW)	(mg GAE/g DW)
A. annua					
Flowers[y]	1,196	38.0	3.0	1,234	51.0
Leaves[y]	1,090	34.6	3.2	1,125	40.5
Stems[y]	288	4.0	1.4	292	18.0
Roots[y]	284	2.6	0.9	287	13.6
Water extract (Br.)	2,123	ND	-	ND	72.0[x]
EtOH extract (Br.)	2,535	ND	-	ND	77.5[x]
EtOH extract (Ch.)	1,960	ND	-	ND	86.0[x]
FD leaves (Sw.)	1,029.0	58.6	5.4	1,087	ND
OD leaves (Sw.)	1,042.0	39.6	3.7	1,082	ND
Artemisia afra	2,052	43	2.1	2,095	ND
A.vulgaris	370.5	34.6	8.0	405.1	ND
A. absinthium	183.1	87.3	32.3	270.4	ND
Oreganum [w]	2,820	18.3	0.65	2,839	66.8
FORAGES					
Lespedeza tops	530.2	9.3	1.7	539.5	ND
***Lotus* sp. tops (trefoil)**	323.4	5.8	1.8	329.2	ND
Switchgrass	316.5	14.58	4.4	331.12	51.7[x]
Alfalfa hay	166	6.0	3.6	172	12.3

[z] ND – Not determined, Br – Brazilian cultivar, Ch. – Chinese cultivar, Sw. – Swiss cultivar, EtOH – Ethanol, FD – Freeze dried, OD – Oven dried.

[y]Data from (Brisibe et al., 2009).

[x]Determined by the Prussian blue Method.

[w]Greenhouse-cultivated oregano at the AFSRC.

pressure. Potassium was also the main mineral found in *A. annua* leaves cultivated in an Appalachian soil (Ferreira, 2007).

Anti-parasitic activity

Artemisia species with reported anthelmintic and anti-parasitic activity are presented in Table 2. Although results vary according to the parasite model used, life stage of the parasite, and host animal tested, it is clear that polar extracts obtained with water or ethanol have a greater anthelmintic activity than non-polar extracts obtained with hexane, which usually have low or no anthelmintic activity. These results indicate that antioxidant flavonoids (hydrophilic fraction) might play a role in anthelmintic activity.

Although some artemisias had promising anthelmintic effects, their possible neurotoxic effects should be kept in mind such as those of *A. absinthium* in rats, if provided in doses higher than 2% of a commercial extract in drinking water (Mukinda and Syce, 2007) and those of *A. afra* aqueous extract which, although non-lethal at 1g/kg of body weight, induced under-activity, diarrhea, and salivation in rats (Mukinda and Syce, 2007). This indicates that oral doses lower than 1g/kg of body weight must be used when testing *A. afra* anthelmintic effects in animals to prevent undesirable effects. However, oral doses of 1.0 and 2.0g/kg of body weight of *A. absinthium* aqueous and ethanolic extract significantly reduced FEC in sheep infected with a mixture of gastrointestinal nematodes, without apparent toxicity to the animals. In vitro, both extracts reduced the motility of *Haemonchus contortus* at 25 mg/mL (Tariq et al., 2009), and both aqueous and ethanolic extracts were effective in vitro and in vivo, but ethanolic outperformed the aqueous extracts. These results agree with others (Urban et al., 2008) who found that ethanolic extracts of *A. absinthium* significantly reduced egg development and juvenile (L3) larval motility of *Ascaris suum* in vitro.

In a previous experiment in collaboration with Drs. Hart and Dr. Wang (American Institute of Goat Research, Langston, OK), goats infected with GIN and fed *A. ludoviciana* flowering tops and *A. annua* leaves for four or six days, respectively, showed a 34% and 4% decrease in FEC, respectively, 14 days after treatments started, while control animals showed a 32% increase in FEC (Hart et al., 2008). This study indicates that *A. ludoviciana* might have a better anthelmintic activity than *A. annua*, but the study should be repeated with both species at the same developmental stage (vegetative or flowering) and also using ethanolic crude extracts instead of only crushed leaves. *Artemisia annua* leaves were found to have similar in vitro organic matter (IVOM) disappearance as alfalfa (63% vs. 67%) indicating that artemisinin (determined as 1.4% on a dry matter basis) did not impair ruminal microflora or overall digestibility in goats (Turner and Ferreira, 2005). The same authors tested oral artemisinin at 10 mg/kg body weight for six days in Boer goats artificially infected with *Haemonchus contortus*, but found no significant reduction in FEC between infected and control, untreated, goats. Although the dose was later determined to be too low to be effective, the data showed a slight decrease in FEC of artemisinin-treated animals compared to a slight increase in FEC in infected, untreated goats. One should also keep in mind that *Haemonchus contortus* is a very resilient nematode that sets high standards for anthelmintic screening with plant-derived compounds.

Tests done in collaboration with Dr. Anne Zajac (Virginia Tech), and using gerbils (a small rodent) artificially infected with *Haemonchus contortus* and treated with artemisinin alone have not reproduced the results obtained for artemisinin drugs in mice or sheep infected with *Schistosoma* and *Fasciola*, respectively, while results with crude *Artemisia* spp. extracts and its essential oil are still to be evaluated. In vitro tests with some individual compounds that occur in *A. annua* and crude ethanolic extracts of *A. annua* have shown some potential to inhibit the motility of *Haemonchus* larvae (Dr. Joyce Foster, personal communication).

Currently, in vitro anthelmintic results, obtained with artemisinin elsewhere, could not be reproduced with *A. annua* in the gerbil model system. Although this might indicate that *A. annua* has no effect on *Haemonchus* and that other species should be tested, it could also mean that: 1) doses tested so far are too low to be effective, 2) the gerbil system does not host *Haemonchus* long enough (only 9 days) for the treatment to produce an effect (animals treated for 5 days only), and 3) the relationship between metabolized plant secondary metabolites and *Haemonchus* might be different in goats and sheep (polygastric ruminants) than in gerbils (a monogastric rodent) infected with the parasite.

Table 2. Anthelmintic activity of artemisia species, artemisinin, and *A. annua* essential oil on internal parasites of animals and humans studied in vitro (parasite outside of host) or in vivo in different hosts, such as mice and sheep.

ARTEMISIA SPECIES	ORGANISM (ANIMAL)	REFERENCE
A. annua (Oil)	*Enterococcus* sp. (in vitro)	(Juteau et al., 2002)
A. annua/ (artemisinin)	*Schistossoma* (mice); coccidia (chicken); *Fasciola* (sheep); *Chlonorchis* sp (rat); *Fasciola gigantic*a (in vitro)	(Allen et al., 1998; Keiser et al., 2008; Keiser et al., 2006; Shalaby et al., 2009; Utzinger et al., 2002)
A. afra	Coccidia (chicken); *C. elegans*(in vitro)	(McGaw et al., 2000; Naidoo et al., 2008)
A. absinthium	Nematodes (soil), *Haemonchus* (sheep), *Trichinella* (rat)	(Caner et al., 2008; Korayem et al., 1993; Tariq et al., 2009; Urban et al., 2008)
A. brevifolia	sheep	(Iqbal et al., 2004)
A. capillaris	*Angiostrongylus (mice)*	(Lai, 2006)
A. herba-alba	*Haemonchus* (goats)	(Idris et al., 1982)
A. maritima	*Haemonchus* (cattle)	(Jangde et al., 2001)
A. santonica	*Ascaris lumbricoids* (in vitro)	(El Garhy and Mahmoud, 2002)
A. sativum	*A. suum, Tricghostrongylus(*in vitro*)*	(Urban et al., 2008)
A. sieberi	Coccidia (chicken)	(Allen et al., 1998; Arab et al., 2006)
A. siversiana	Tapeworm (mice)	(Singhal, 1983)
A. vulgaris	*Trichinella spiralis* (rat)	(Caner et al., 2008)

Conclusions

Although plants are being investigated and referred to as alternative therapies for failing synthetic anthelmintic, antimalarial, and anti-bacterial drugs, it unlikely that these plants will ever replace pharmaceutical drugs currently in use. However, they have the potential to decrease the use these drugs or make them more effective, if used in combination.

Several articles dealing with the anthelmintic effects of plants exist, but only few articles approach the use of these plants in combined therapy with synthetic drugs to treat multi-drug resistant nematodes. Recently, the extract of *Artemisia capillaris* was shown to have synergistic effect when used with albendazole against *Angiostrongylus cantonensis* at 100mg/kg/day, for 7 days. The concept of synergism is not new and focuses on using crude plant extracts (several compounds together) instead of one active component (natural or synthetic). Synergism has been better studied in parasitic diseases that kill millions of people every year, such as malaria. For instance, artemisinin present in traditional teas has been shown to have similar antimalarial effects than pure artemisinin as a drug, although the tea contains one third of the concentration used in artemisinin antimalarial drugs. This effect is attributed to the tea flavonoids, which potentiate artemisinin effect. The *A. annua* bioactive flavonoids chrysosplenol-D and chrysoplenetin showed week activity against a drug-resistant strain of the *Staphylococcus aureus* bacteria, but were remarkably bactericidal when combined with berberin (a plant alkaloid) and the drug norfloxacin, indicating that these natural compounds rendered the drug-resistant bacteria susceptible to norfloxacin again (Stermitz et al., 2002). Currently, artemisinin (as artemether) is recommended by the World Health Organization as a combination therapy, with a synthetic antimalarial drug (lumefantrine), as the first-line antimalarial treatment in over 50 countries afflicted by chloroquine-resistant malaria. The use of artemisinin alone is not recommended. Both the combinations of artemisinin with quinine and artemisinin with curcumin (all plant compounds) showed synergistic effect against malaria in vitro (Gupta et al., 2002; Nandakumar et al., 2006) and in mice (Nandakumar et al., 2006). Polyphenolic compounds from tea such as epigallocatechin gallate and epicatechin gallate had antimalarial effects on their own, and improved the antimalarial effects of artemisinin (Sannella et al., 2007). Schistosomiasis, caused by a blood trematode, is controlled successfully in South Africa by crude plant extracts where

21 plant species showed in vitro activity at 50mg/ml of the aqueous extract, killing 66-100% of the juvenile worms (schistosomula), with 9/21 plants being lethal at 25mg/ml, and 6/21 plants being lethal at 6.25mg/ml (Sparg et al., 2000). Synergism have been gaining momentum in the past 15 years and have been documented for several herbs through tests in vitro and in vivo and have been reviewed elsewhere (Williamson, 2001).

The accumulating and compelling evidence in the literature, and the lack of promising results obtained so far with artemisinin alone against *Haemonchus*, indicate that crude herbal extracts, herbal combinations, and the combination of herbal extracts and anthelmintic drugs need to be tested for their potential combined effects against gastrointestinal nematodes.

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Dr. Joyce G. Foster received her and Ph.D. degrees in biochemistry and nutrition from Virginia Tech in 1979. Her graduate research concerned environmental regulation of antioxidant enzymes in plant leaves. She conducted postdoctoral research at the University of Wisconsin-Madison and Washington State University, investigating compartmentalization and regulation of photosynthetic enzymes in C3, C4, and CAM plants. She joined the USDA, ARS facility in Beaver, WV, in 1982. Her investigations of the forage potential of flatpea involved developing methods to extract and quantify natural products, identifying environmental factors that influence natural product concentrations in herbage, and describing signs of flatpea toxicity in sheep. Subsequently her research centered on non-traditional herbaceous and woody plants for finishing meat goats in temperate climates. Current emphasis is on plant secondary metabolites with potential to disrupt the life cycle of the gastrointestinal parasite *Haemonchus contortus*.

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